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DESIGN AND DEVELOPMENT OF AN AIR-EJECTOR POWERED PNEUMATIC SURFACE SAMPLING SYSTEM

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FOREWORD

The work described in this report was authorized by the Jet Propulsion Laboratory, under Contract No. 950771, Mars Biological Sample Collection and Processing Study Program and was performed under the direction of Dr. G. Soffen and Mr. J. Stuart. This report is an addendum to the final report which was published in February 1965, on sample acquisition and biological support studies.

ABSTRACT

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A pneumatic surface sampling system for use under simulated Martian environmental conditions has been designed, fabricated and tested. This unit relies upon the phenomena of air blast dislodgment of surface particles by an external, traversing sampler head, pneumatic transport of particulate material to the main sampler body, and subsequent centrifugal separation by a cyclone collector. It is capable of operation with particles as large as 800 microns diameter at ambient pressures as low as 5 millibars and at ambient temperatures down to -60°C. In tests with sandy soils the collection rate of this device is on the order of 15 grams per minute for periods up to 10 minutes. Biological assessment has shown the acquired samples are representative of the environment.

author

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DESIGN AND DEVELOPMENT OF AN AIR-EJECTOR POWERED PNEUMATIC SURFACE SAMPLING SYSTEM

1. INTRODUCTION

This report describes a sampling system developed and built to demonstrate the feasibility of utilizing a pneumatic system for acquiring a surface sample under simulated Martian conditions. The only electrical energy employed in the system is for activating the controls. This sampling system is capable of operating in a temperature range of -60 to +40°C with an ambient pressure as low as 5 millibars and capable of collecting from a dry, sandy surface a 15-gram sample per minute. The system has a range of 10 feet and an operation period of 10 minutes. Sand particles as large 800 microns have been successfully transported by the system.

During the performance of this program, the Mariner fly-by of Mars was successfully concluded and one of the results was a revision of the estimated Martian pressure to the neighborhood of 5 millibars. Since Martian application is of prime importance to this sampling system, most of the information and data presented in this report are for a pressure of 5 millibars. Operational data up to a pressure of 100 millibars are included as required in the contract.

2. SYSTEM DESCRIPTION AND OPERATION

The object of this section is to describe the sampling system, which is called the penumatic sampler, and its general operational characteristics. Details regarding the design and component selection are given in Section 3 on Design Development.

A photograph and a schematic diagram of the penumatic sampler are presented in Figures 1 and 2, respectively. The overall dimensions of the unit are 14 by 9-3/8 by 12 inches, for length, width and height, respectively, which gives a volume of 0.91 cubic feet. The weight of the unit is 3.5 pounds, excluding the gas reservoir and supply. A description of each major subsystem and the operation of the system are given in the subsequent sections. The major subsystems are:

1) Sampler Head
2) Transport
3) Ejection
4) Retrieval
5) Air Ejector and Cyclone Separator
6) Gas Supply.

A complete set of engineering drawings and specifications have been prepared for the penumatic sampler and, consequently, the material presented in this section is intended only to provide an understanding of the sampler and its operation.

2.1 Sampler Head

The function of the sampler head is to aerosolize the soil and supply a sample of fluidized particulates to the transport tube. A photograph of the sampler head is given in Figure 3. The sampler

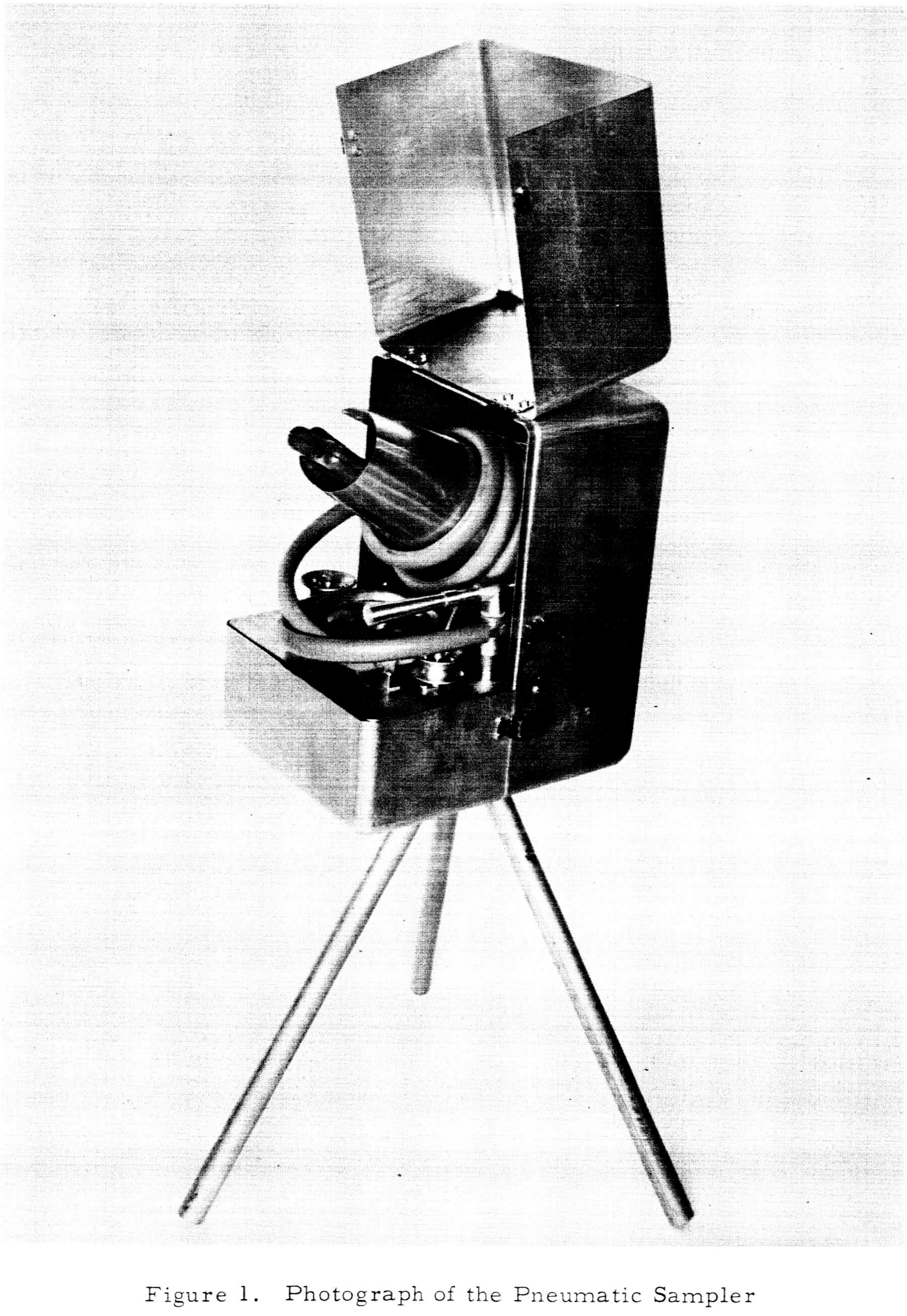


Figure 1. Photograph of the Pneumatic Sampler

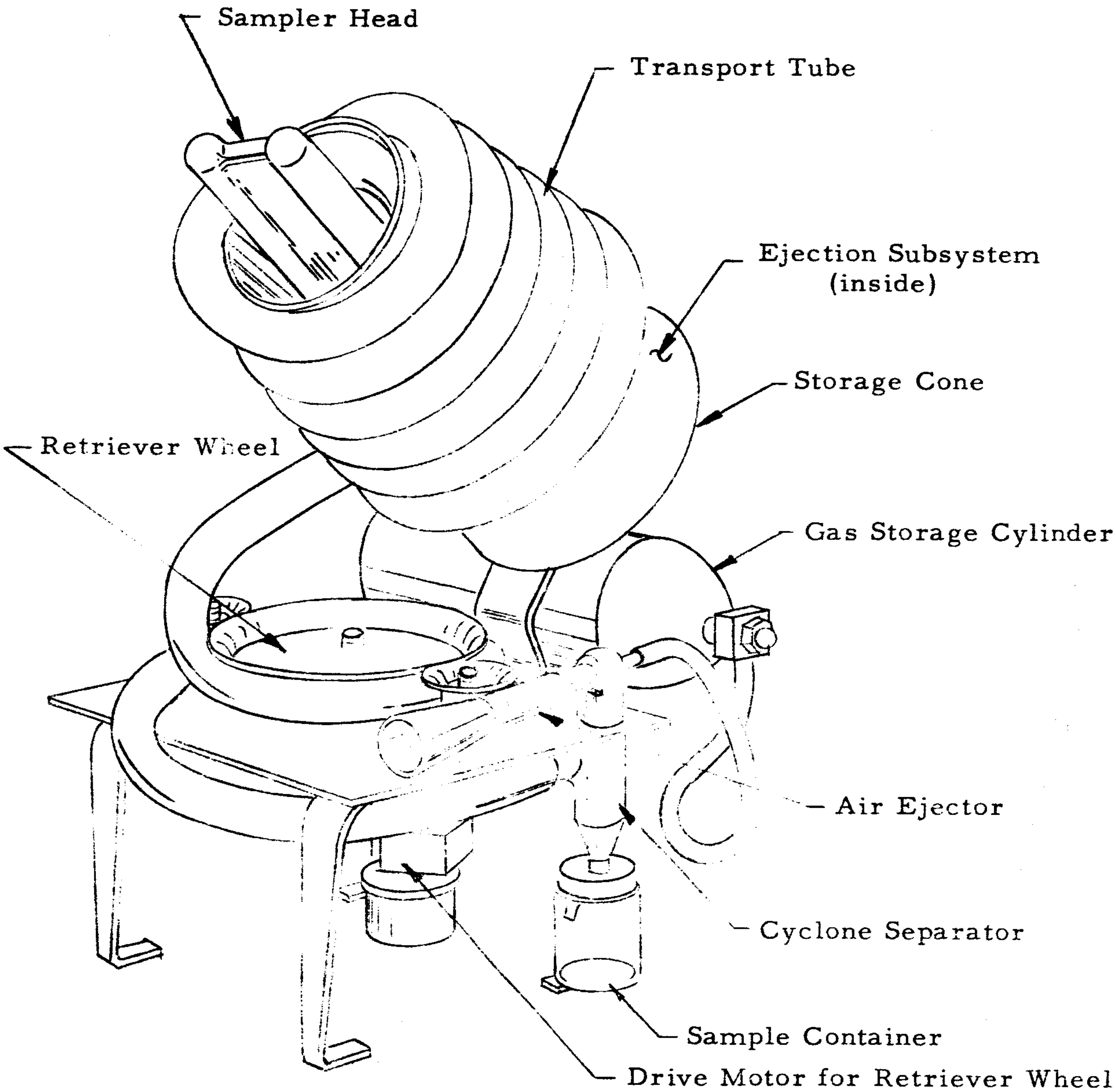


Figure 2. Schematic Diagram of the Pneumatic Sampler

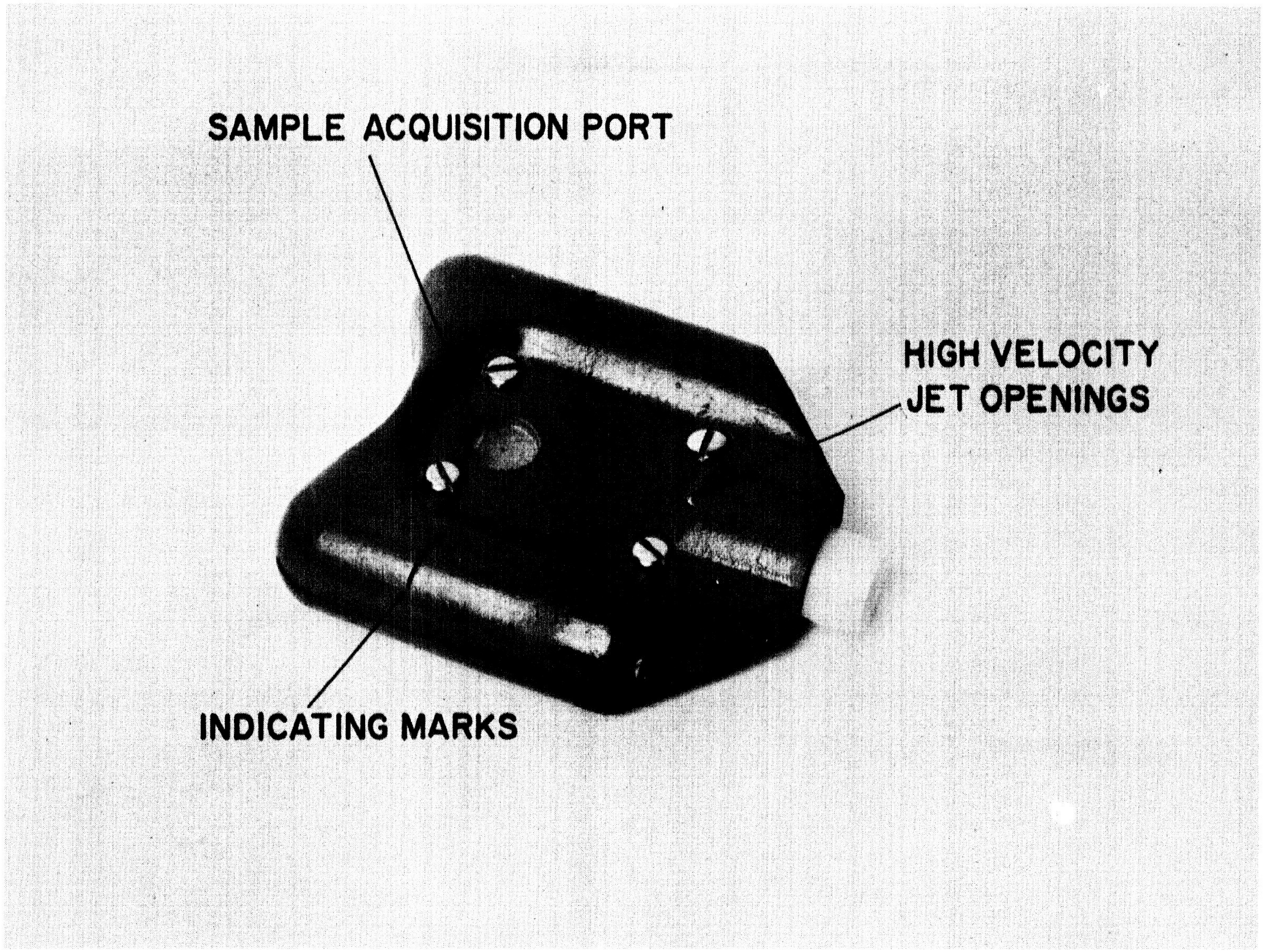


Figure 3. Photograph of the Sampler Head

head consists of a fiberglass shell which houses the following components:

1) Two CO_2 cartridges

2) Two high-velocity jets

3) A pivoted closure

4) A transport tubing connection.

These components are shown in Figure 4, a photograph of the sampler head with the upper half section of the shell removed.

The shell of the sampler head is fabricated from an epoxy reinforced with a glass cloth. The shell including the other components of the head have been designed to withstand the shock associated with the impact due to landing on a hard surface. The shell is made of two identical pieces which fasten together with screws.

The overall dimensions of the sampler head are given in the drawings and can easily be estimated from Figure 4 , by comparison with the inch markings on the meter. As is discussed in Section 3.2 on Design Development, the critical exterior dimensions of the sampler head are: 1) the distance between the sample acquisition port and the surface, and 2) the cross-sectional area normal to the ambient gas flow which is formed by the sampler head and the surface. These values are 7/32 inch and 0.25 square inch.

The propulsion of the sampler head is accomplished with two small CO_2 cartridges which are 3/4 inch in diameter, 2-1/2 inches long and contain a quantity of CO_2 equal to 8.5 grams. Figure 4 shows these cartridges inside the sampler head.

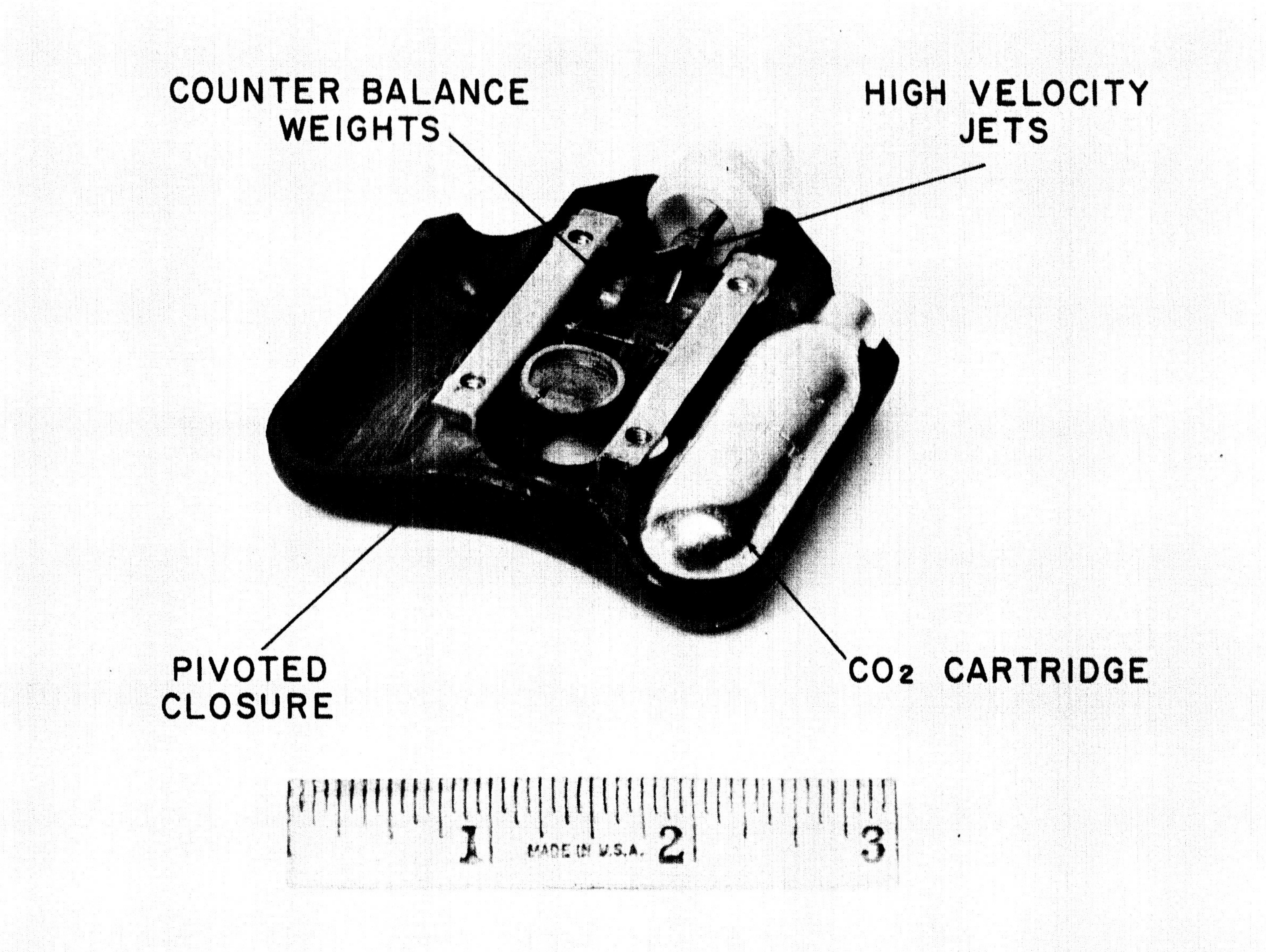


Figure 4. Photograph of the Lower Section of the Sampler Head

The function of the pivoted closure shown in Figure 4 is to seal the top sample acquisition port so that the ambient gas must flow under the sampler head and into the lower sample acquisition port regardless of position. The pivoted closure consists of a sealing disc with the flat surfaces machined to form a wedge-shaped piece for sealing. This piece is mounted on one end of a pivoted H-shaped frame; on the other end of the H frame are mounted two lead weights for counterbalancing the sealing disc. This frame is mounted between the assembly channels of the sampler head in a position such that the sealing disc covers the upper sample acquisition port. When the sampler head is inverted, the counterbalance weights move the sealing disc into the upper position so that only the bottom sample acquisition port is open.

The sampler head is designed to operate properly regardless of which side of the head lands on the surface. Proper operation is insured, since the sample acquisition port on the top side of the sampler is always sealed by the pivoted closure and the location of high-velocity jets on both the top and bottom of the sampler head provides aerosolization, regardless of orientation. The transport tube is attached to the sampler head by a nylon swivel so that the sampler head can easily orient itself to any surface.

2.2 Transport Subsystem

The functions of the transport subsystem are:

1) To transport the particles from the sampler head to the cyclone separator

2) To supply an adequate gas flow to the high-velocity jets.

The transport subsystem consists of two tubes and a cone for storing the tubing. The tubes consist of one relatively large tube to transport the particles and a much smaller tube which is located inside the larger tube for supplying gas to the high-velocity jets. The transport tubing and aluminum cone can be seen in Figure 1, a photograph, and Figure 2, a schematic diagram of the sampler.

The transport and high-velocity tubes are made of a silicone rubber compound (DC 747) manufactured by Dow Corning and have a Durometer Hardness Shore A Scale of 70. Ten feet of transport tubing with a 1/2-inch I. D. was selected for this system. This diameter is based on a gas velocity of 3000 feet per minute which is sufficient to give a 100 percent transport efficiency for a 100-micron particle having a density of 2.6 grams per cubic centimeter. The high-velocity tube located inside the transport tube has a 1/8-inch O. D. and a 1/16-inch I. D. and supplies 0.08 cfm at a pressure of 800 millibars to the high-velocity jets.

In the ready condition, the tubing is wrapped on the outside of the aluminum cone as is shown in Figures 1 and 2. The cone is 6 inches in diameter at the large end, 3 inches in diameter at the small end and 10 inches in length. This configuration produces satisfactory ejection of the sampler head and transport tubing when the cone is elevated 30 degrees with respect to the horizontal. The elevation is important since the sampler head must strike the surface before the transport tube is fully extended to prevent the sampler head from "snapping back" and reducing the effective range.

2.3 Ejection Subsystem

The purpose of the ejection subsystem is to eject the sampler head and the trailing transport tubing a distance of 10 feet from the main unit before sampling is started. This ejection operation is accomplished by two CO_2 cartridges located in the sampler head which act as rockets and, consequently, the basic function of the ejection subsystem is to penetrate the CO_2 cartridges. A photograph of the ejection subsystem is presented in Figure 5. This subsystem is composed of two primary components — the penetrator mechanism and the activation mechanism.

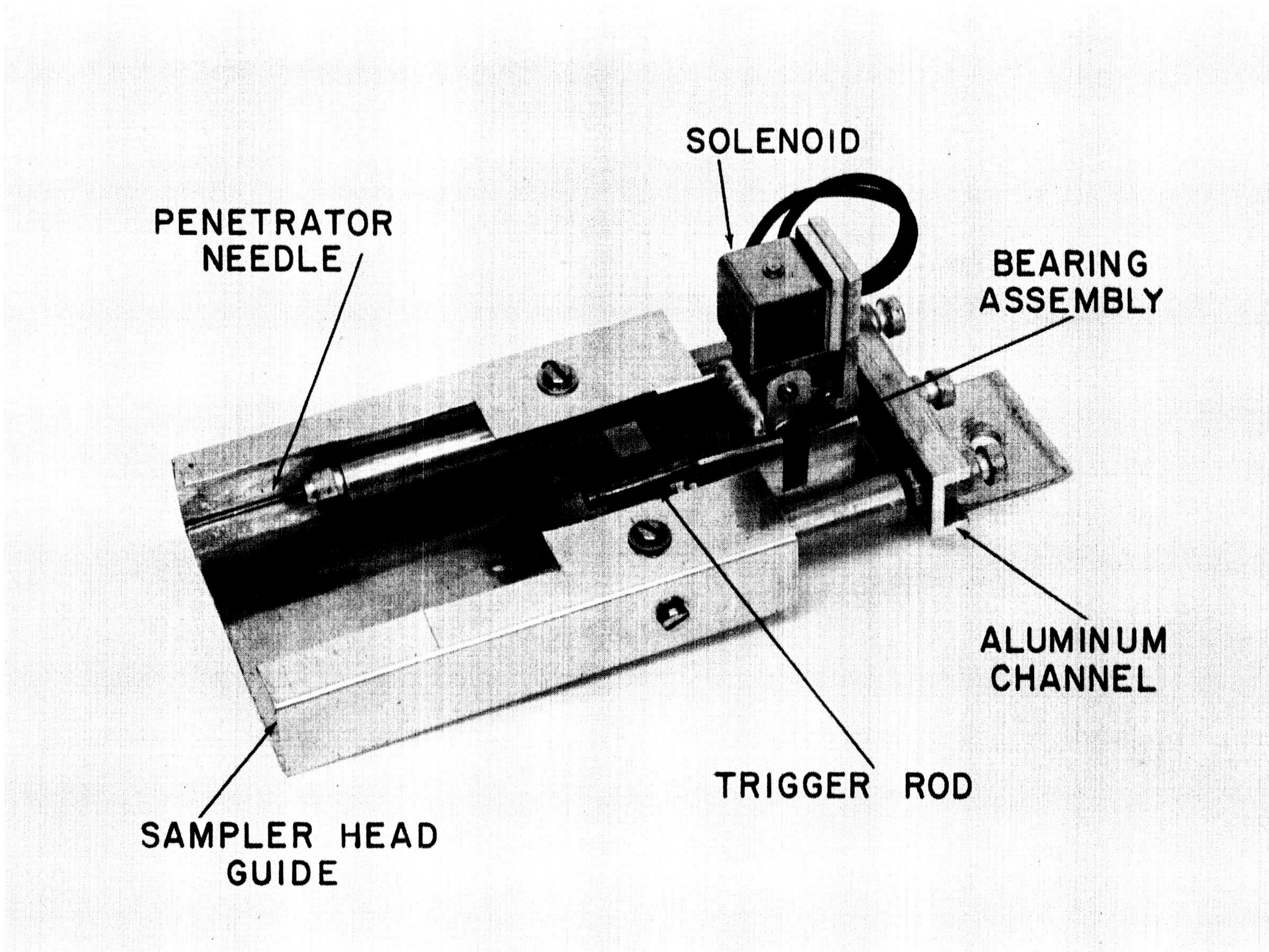


Figure 5. Photograph of Ejection Subsystem

The function of the penetrator mechanism is to properly pierce the CO_2 cartridges. This mechanism consists of two 1/2-inch diameter tubes 4-1/2 inches long which house a set of springs and penetrator rods. The rods are made of 3/16-inch diameter drill rods threaded on both ends. One end of each rod is fitted with an aluminum cap on which is mounted a 0.04-inch diameter steel needle and the other end of the rod is attached to an aluminum channel. The penetrator rods and a center trigger rod are mounted on this aluminum channel to form a single unit. Each penetrator rod is driven by an individual spring which exerts a force on the aluminum channel when the penetrator rods are in the cocked position.

Movement of the trigger rod is controlled by the activation mechanism which releases the penetrator. The activation mechanism consists of an electrical solenoid and a triggering rod unit.

This latter rod unit consists of a trigger rod and three ball bearings mounted on a shaft attached to the solenoid. The ball bearings and shaft (bearing assembly) are housed in a 1-inch square frame through which the trigger rod passes. These components are shown in Figure 5. The two outer bearings are in contact with the frame while the center bearing makes contact only with the trigger rod. If the solenoid is not energized, the center bearing of the bearing assembly rests in front of the trigger rod and prevents it and the aluminum channel from moving forward. When the solenoid is energized, the bearing assembly moves further into the frame releasing the trigger rod. The aluminum channel with the attached penetrator rods now moves forward due to the spring force until the needles on the penetrator rods pierce the CO_2 cartridges. At this time the sampler head is ejected.

2.4 Retrieval Subsystem

The retrieval subsystem returns the sampler head at a constant rate of 12 inches per minute from its ejected position to the main unit. The ejection subsystem is required to eject the sampler head a distance of 10 feet. Two photographs of the retrieval subsystem are given in Figures 6 and 7. The principal components of the subsystem are a starting solenoid, a governor, a speed reducer, a drive motor, a retriever wheel, two idler wheels and a guide cone.

When the starting solenoid is energized it activates the drive motor which retrieves the transport tubing and sampler head. This drive motor is a wound spring with a constant torque output. The pertinent characteristics of the spring for this motor are as follows:

Weight	10.5 oz
Impact Torque	6.5 in./lb
Output Torque	6.0 in./lb
Speed of Tubing	15.5 in./min
Pull of Tubing	6.0 lb.

The sampler is designed so that a larger spring motor can be installed by modifying the fittings. This motor will operate for a period of 10 minutes after the start of the sampling operation.

Since the sampler head must be retrieved at a constant rate of 12 inches per minute, the speed of the drive motor is controlled by a governor. In order to have effective governor control, the speed of the governor is increased above the drive motor speed by driving the governor through a speed reducer. The speed reducer is coupled to the drive motor by a one-direction clutch which permits the motor to be wound without turning the governor. The speed reducer is a ball bearing unit which has a reduction ratio of 175.82 to 1. It is lubricated with 10 centipose silicone oil which permits satisfactory operation at -60°C.

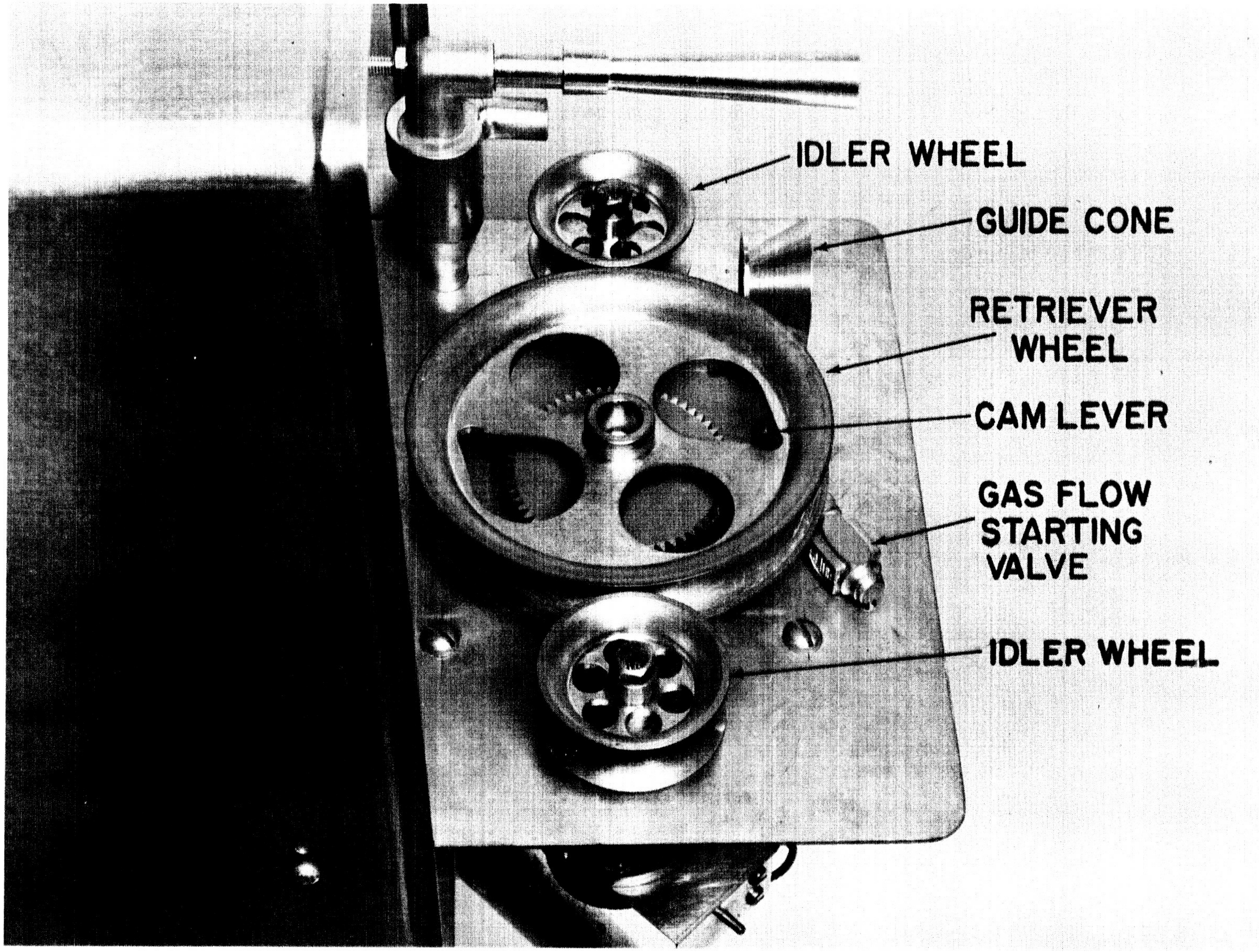


Figure 6. Top View of Retrieved Subsystem

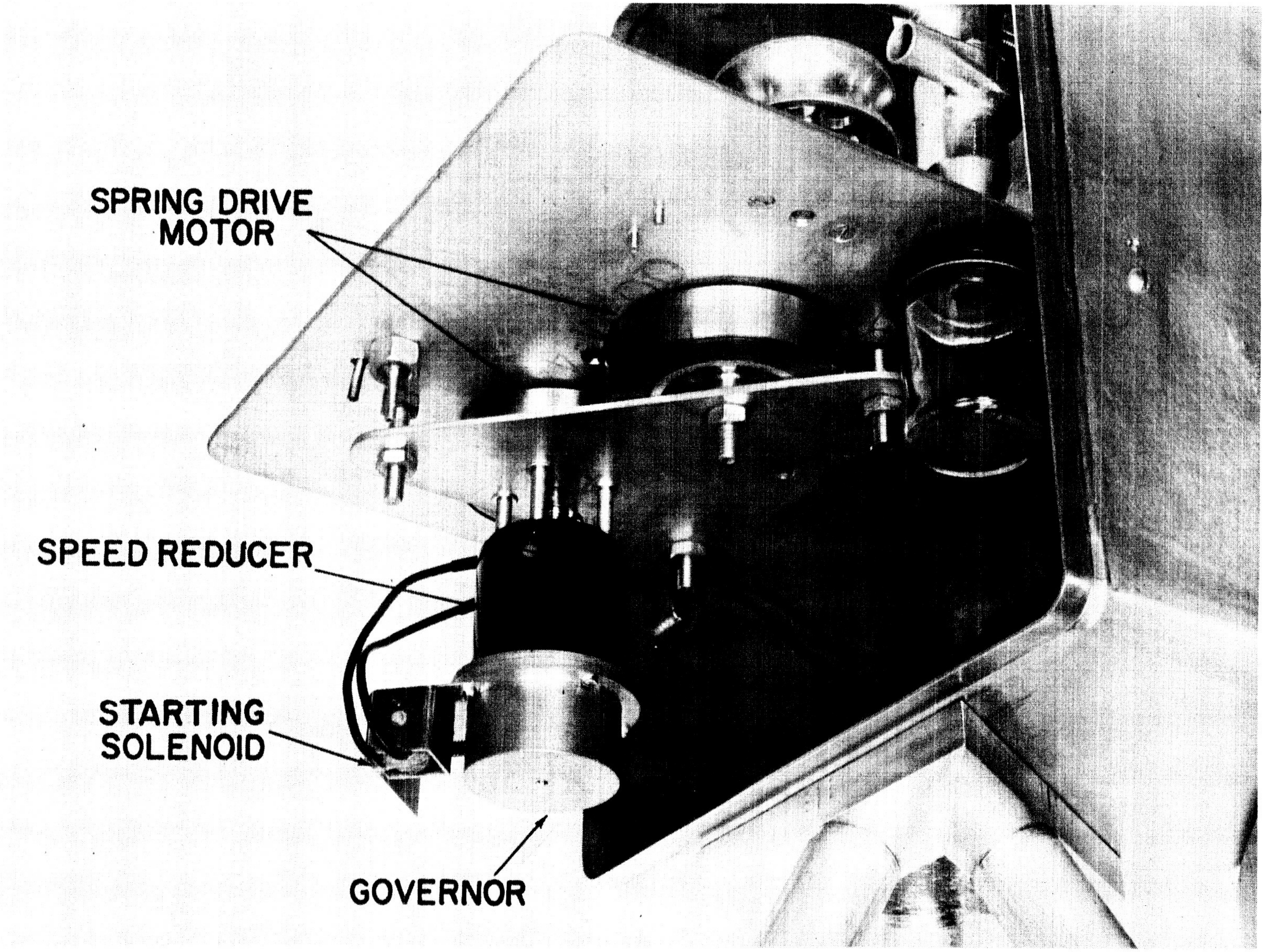


Figure 7. Bottom View of Retrieved Subsystem

The friction-type governor employs two weighted arms with cork-lined shoes which rotate inside a magnesium drum. The drive motor produces a tube transport speed of 15.5 inches per minute, which is greater than the required 12 inches per minute. To reduce the tube speed to the proper value, cork-lined shoes were installed on the governor.

As is shown in Figure 6, a large grooved pulley driven by the drive motor serves as the retriever wheel for the transport tubing. The two small diameter grooved pulleys act as idler wheels. The large pulley has a root diameter of 4 inches and the small pulleys have root diameters of 1-1/2 inches. The small cone located adjacent to the retriever wheels acts as a guide for aligning the transport tubing as it enters the groove between the retriever wheel and the first idler wheel. The transport tubing follows the retriever wheel for 180 degrees of arc, passes between the retriever wheel and the second idler wheel, and at this point leaves the retriever wheel. Since one end of the transport tubing is connected to the cyclone separator inlet, the transport tubing leaving the idler wheel coils onto the surrounding surface. The pulleys and the guide cone are made of magnesium material.

2.5 Air Ejector and Cyclone Separator

The function of the air ejector is to pump a sufficient amount of gas through the transport tube such that a sample of 1 gram per minute will be transported to the cyclone separator, and the function of the cyclone separator is to remove the particles from the gas stream.

A photograph and a schematic diagram of the air ejector and the cyclone separator are given in Figures 8 and 9, respectively. These figures show the relative positions of the air ejector and cyclone separator and the pertinent dimensions. The total angle of the diffuser section on the air ejector is 7 degrees. Design operating conditions for the air ejector are a secondary flow rate of 4.0 cfm for an ambient pressure of 5 millibars and a primary pressure of 800 millibars. The secondary flow rate for the air ejector can be increased by increasing the primary pressure. Both the air ejector and the cyclone separator are made of aluminum.

2.6 Gas Supply Subsystem

The purpose of the gas supply subsystem is to provide a sufficient quantity of gas at a constant pressure to the primary nozzle of the air ejector and to the high-velocity jets in the sampler head. The gas supply subsystem consists of four primary components: a gas storage cylinder, a cylinder shut-off valve, a pressure regulator, and a flow-starting valve. A photograph showing the components with the exception of the flow-starting valve is presented in Figure 10. The flow-starting valve can be seen in Figure 6.

A gas storage cylinder was selected for the sampler system which can be filled with 1.4 pounds of liquid CO_2. This is sufficient for an operational period of 18 minutes at a primary pressure of 800 millibars and an ambient pressure of 5 millibars.

A cylinder shut-off valve is fitted with a tube extending inside and to the top of the storage cylinder such that only gaseous CO_2 can be discharged from the cylinder. The gas pressure at the cylinder exit is controlled by a regulator which is adjustable so that the pressure of the gas as supplied to the air ejector and high-velocity jets can be varied as required for a given ambient pressure.

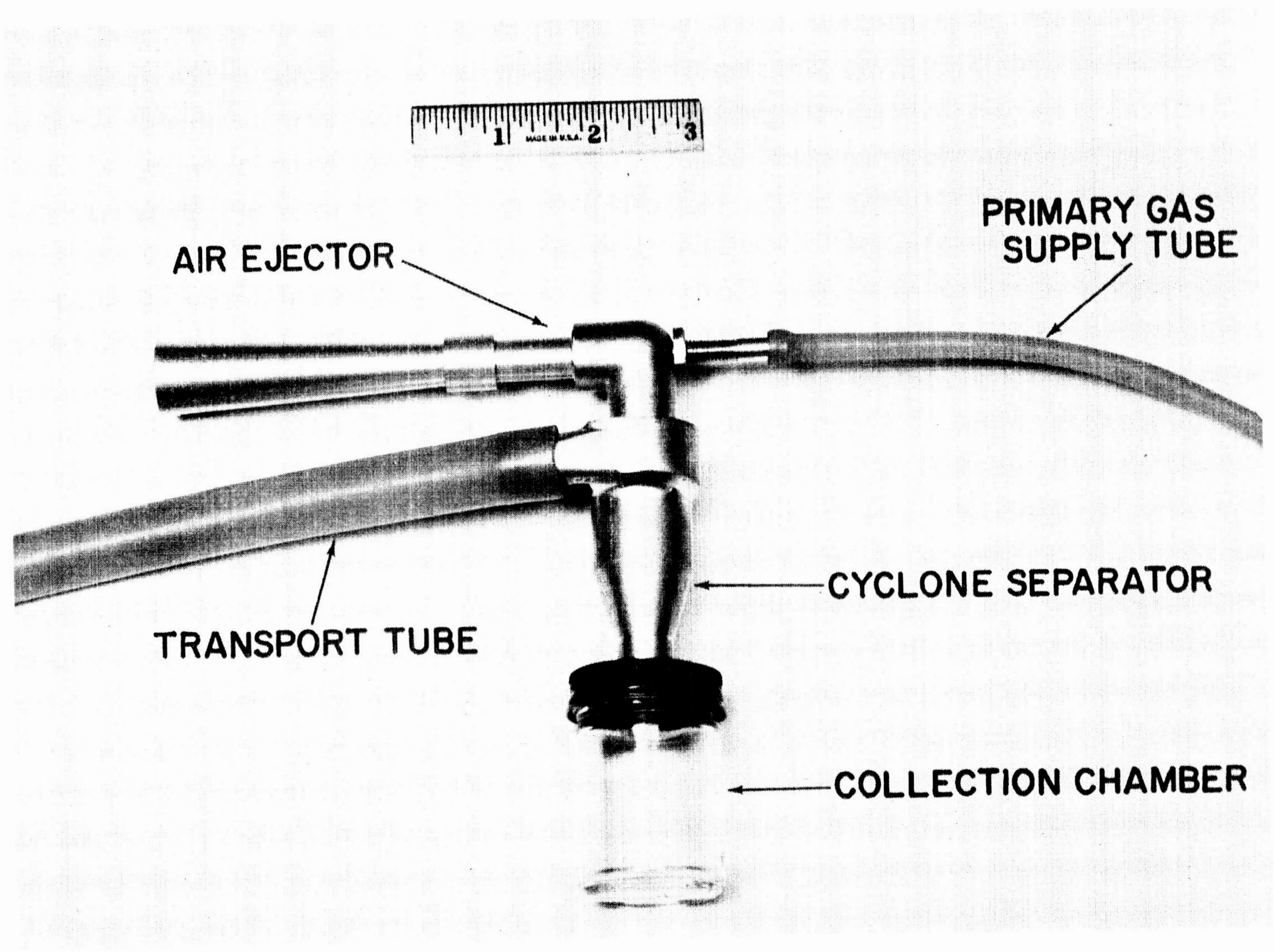


Figure 8. Photograph of Air Ejector and Cyclone Separator

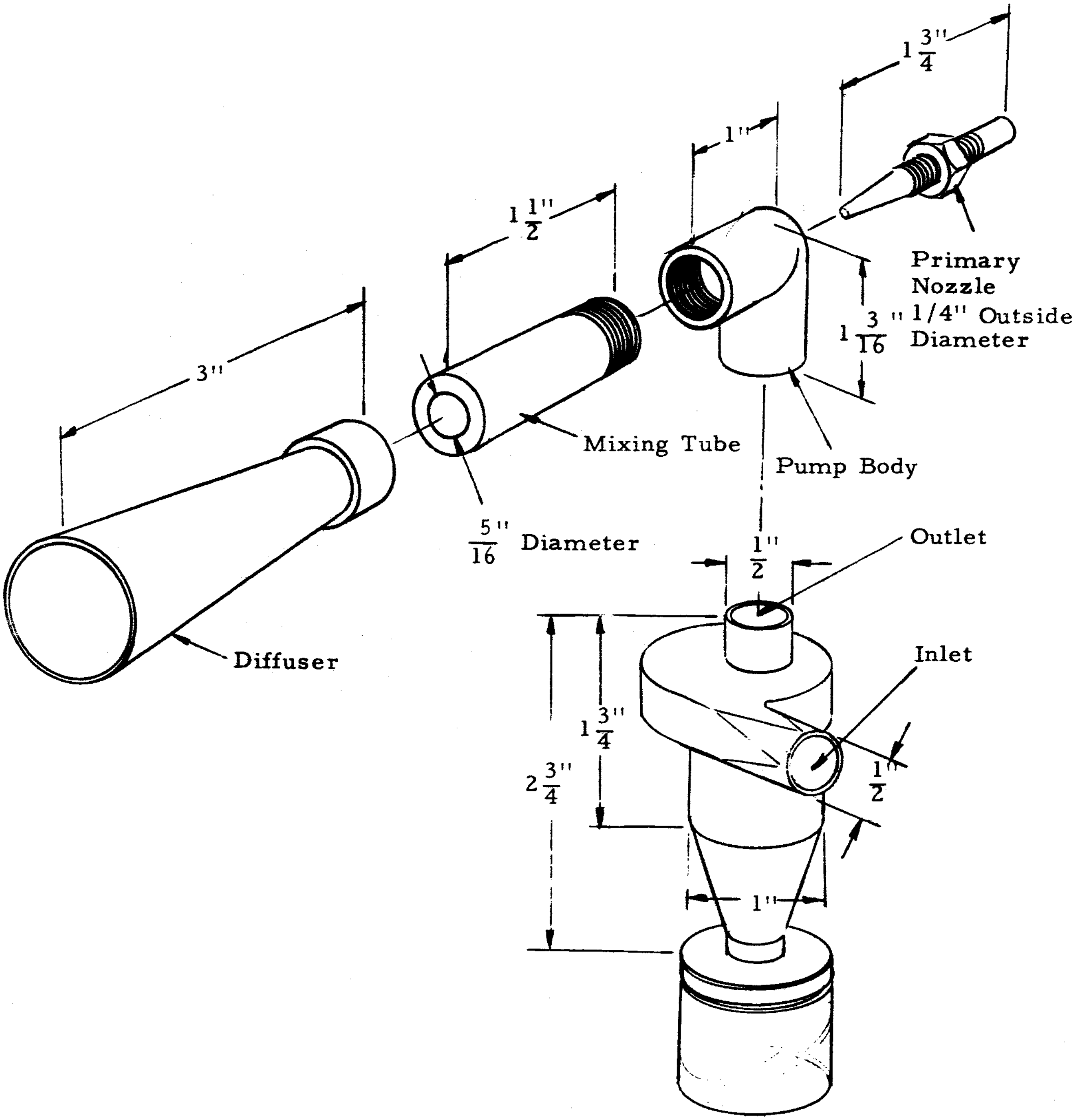


Figure 9. Schematic Diagram of Air Ejector and Cyclone Separator

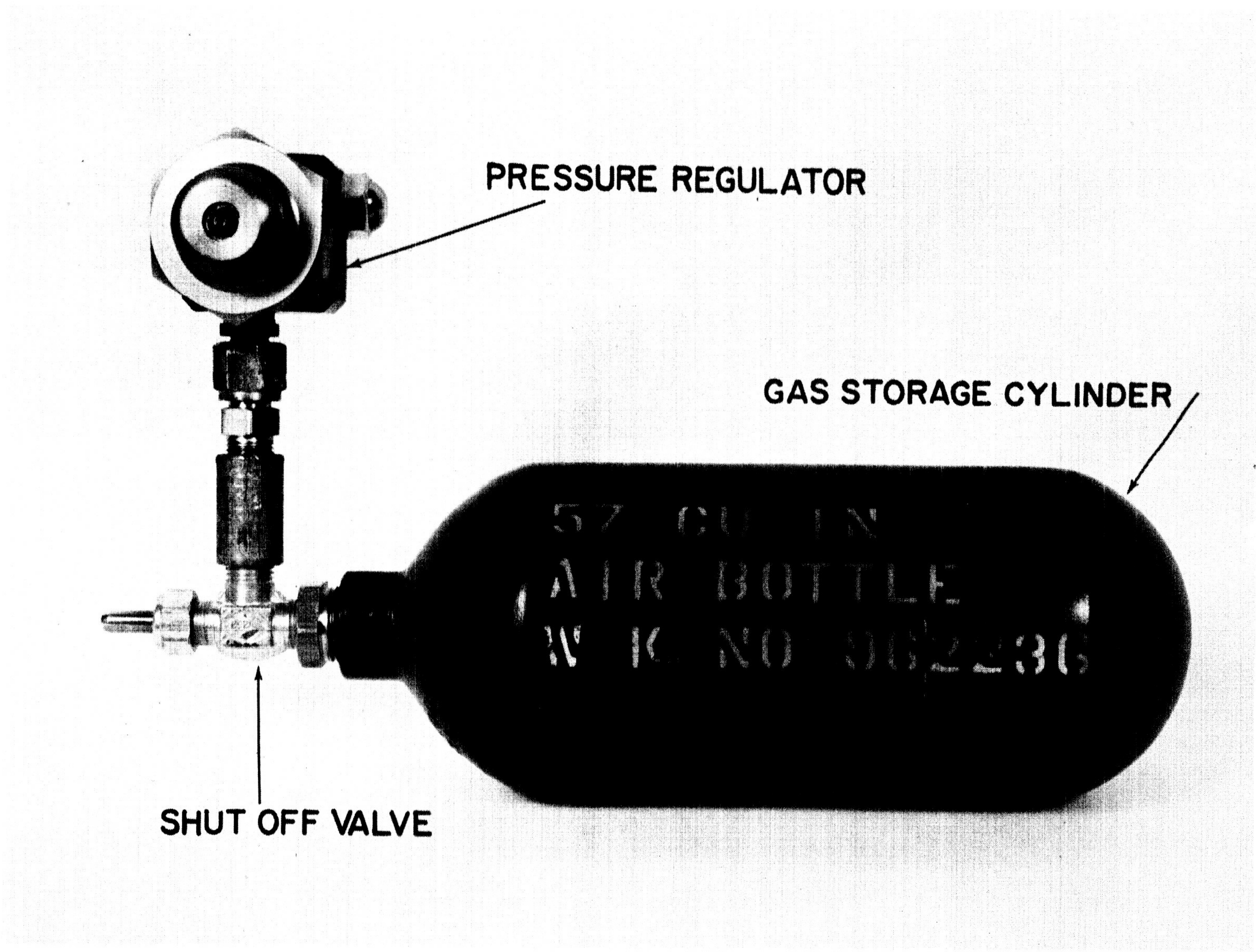


Figure 10. Gas Supply Subsystem

When the retriever mechanism is actuated, the flow-starting valve starts the flow of gas from the cylinder to the ejector and the high-velocity jets. Figure 6 shows the flow-starting valve mounted under the retriever wheel. This valve is actuated by a cam lever which in turn is actuated by the retriever wheel. The location of this cam lever can also be seen in Figure 6.

2.7 System Operation

The operating cycle of the pneumatic sampler consists of several basic steps which are sequentially performed. The preparation of the sampler is discussed in the Appendix. Operating cycle after preparation consists of:

1) Receipt of actuation signal

2) Ejection of sampler head and transport tubing

3) Retrieval of sampler head and transport tubing

4) Soil aerosolization and pneumatic transport during retrieval

5) Soil collection and sample removal during retrieval.

The actuator signal may consist of depressing the starting switch which sends a 24-volt dc pulse to the penetrator mechanism solenoid. When the penetrator rods are released, they strike the two CO_2 cartridges located in the sampler head. The sampler head and attached transport tubing are ejected from the main unit and are propelled approximately 10 feet by the thrust generated from the CO_2 cartridges. A photograph showing the sampler system after the ejection operation is given in Figure 11.

At the same time that the 24-volt dc pulse is received by the solenoid controlling the penetrator mechanism, another solenoid is energized which releases the lock on the drive motor. Releasing this lock permits the wound-spring motor to start driving the retriever wheel. The retriever wheel pulls the sampler head and transport tubing back to the main sampler unit. The returning transport tubing passes through the main sampler unit and is coiled on the surface in front of the sampler. A photograph showing the pneumatic sampler after the transport tubing has been retrieved is given in Figure 12. The transport tubing continues to be retrieved until the sampler head is arrested by the guide cone as shown in Figure 12.

When the sampler system is being prepared for operation the main valve to the gas storage cylinder is turned on; however, the flow-starting valve which is under the retrieving wheel and actuated by the retrieving wheel is in its off-position. As the retrieving wheel begins to rotate it depresses the cam lever of the flow-starting valve and gas begins to flow from the storage cylinder to the air ejector and the high-velocity jets. After this flow-starting valve has been opened it remains open until it is manually closed.

As the gas from the high-velocity jets aerosolize the soil under the sampler head, the soil particles are drawn into the transport tube via the sample acquisition port by the reduced pressure in the transport tube. This reduced pressure is produced by the air ejector.

The soil particles are carried up the transport tube by the secondary flow of the air ejector. At the outlet end of the transport tube the soil particles enter a cyclone separator which serves as the particle recovery unit. The particles are deposited in the collection chamber of the cyclone separator and gas stream flows out of the cyclone and on into the air ejector. In the air ejector the gas stream from the cyclone separator mixes with the primary gas in the mixing

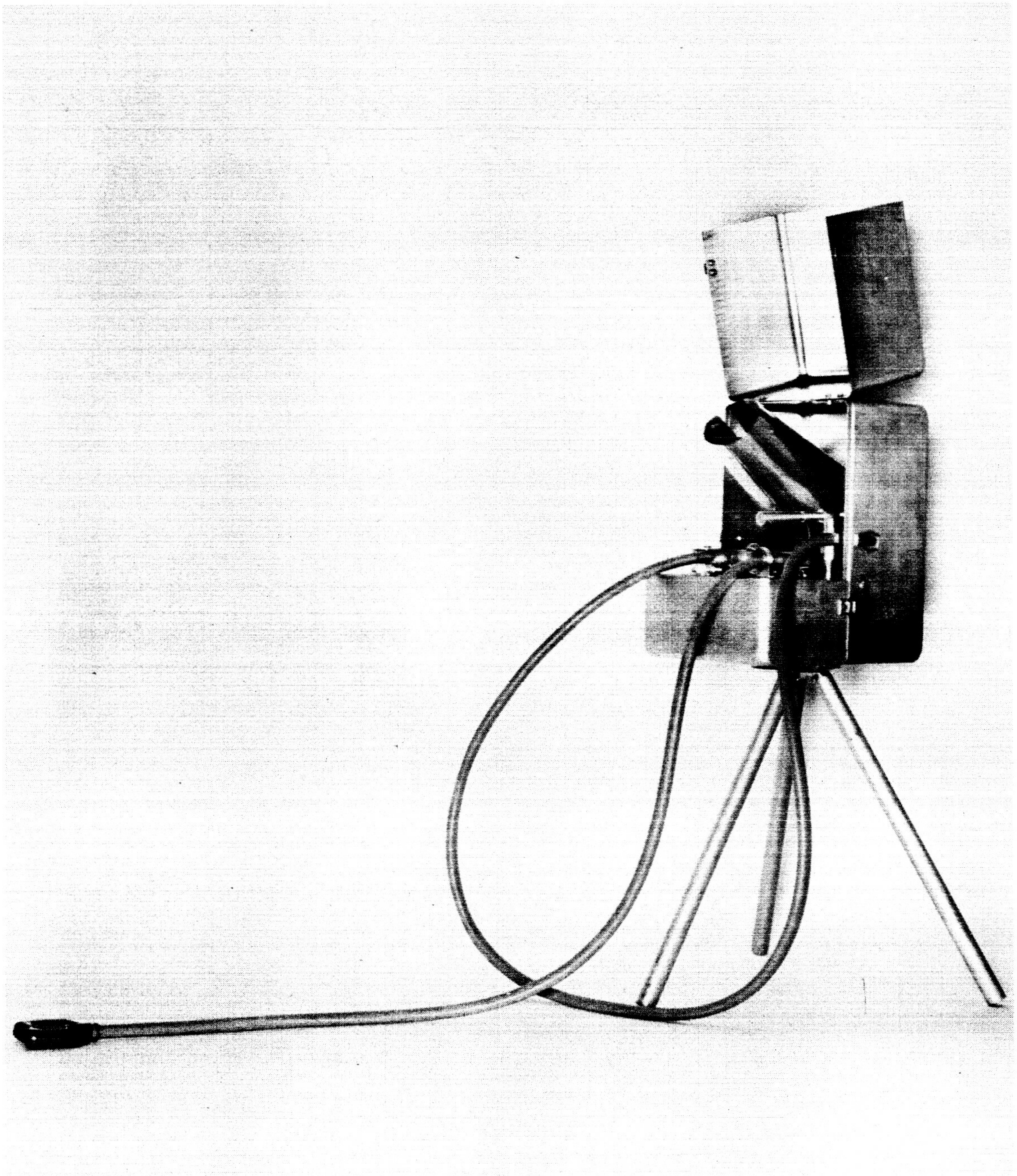


Figure 11. Photograph of Pneumatic Sampler after Ejection

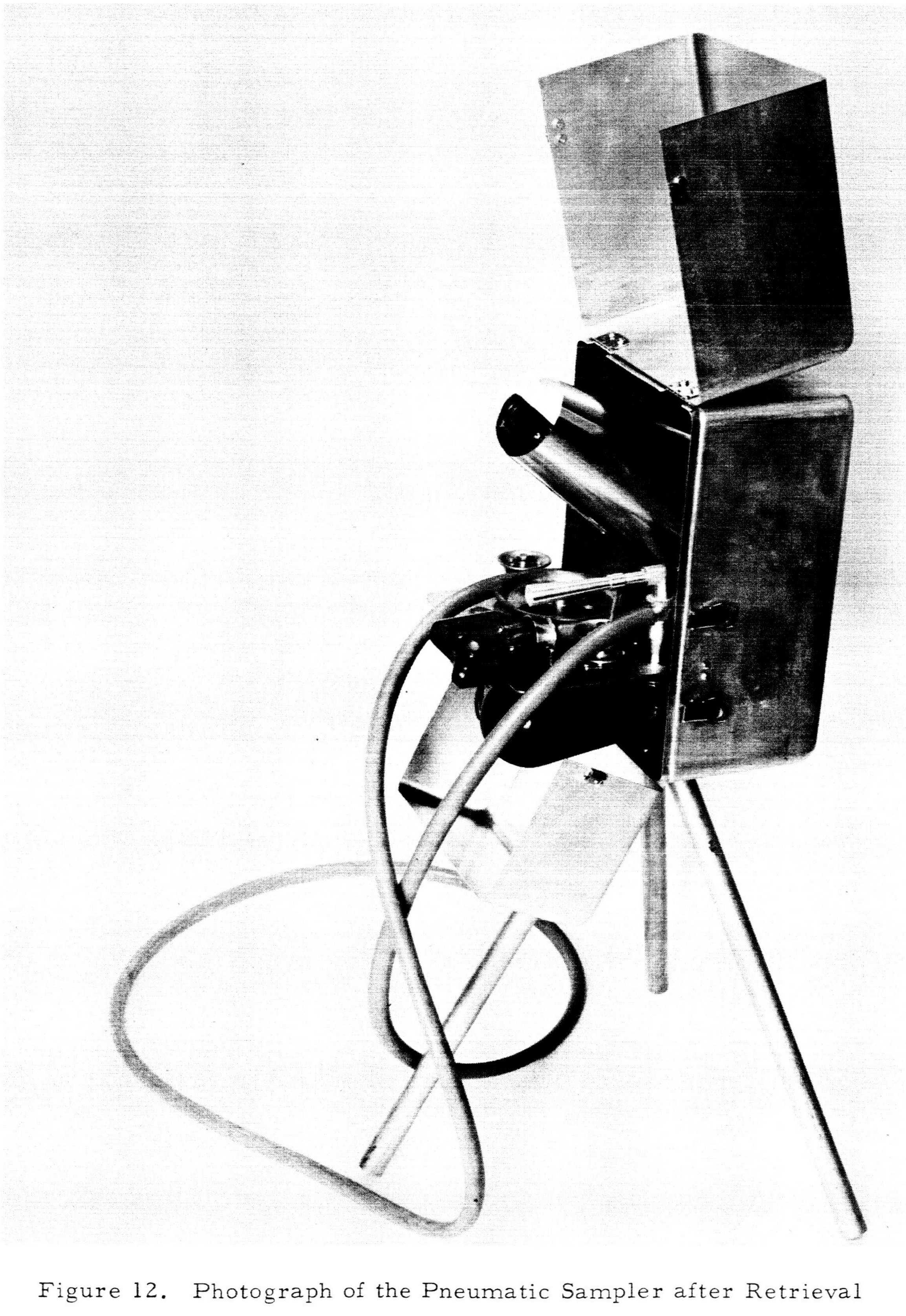


Figure 12. Photograph of the Pneumatic Sampler after Retrieval

tube and then flows out of the air ejector into the surrounding atmosphere. At the end of the sampling period the collection chamber containing the soil particles is removed from the cyclone separator.

3. DESIGN DEVELOPMENT

The purpose of this section is to establish the general philosophy of design that was employed in developing the pneumatic sampler. Specific problems requiring solutions are outlined and the relevant aspects of the work are presented. The majority of the development work was accomplished during the first phase of this program and was presented in the final report;[1] however, for convenience and completeness, the applicable aspects of the work reported in the final report are presented in this section along with the additional work that was done during this current phase of the program.

In developing the pneumatic sampler, the following four major problems required solutions:

1) Traversing the surface from which the soil particles are to be acquired with a particle collection apparatus

2) Effectively aerosolizing the soil particles at the place of sample acquisition

3) Pneumatically transporting the aerosolized particles from the place of sample acquisition to the particle separator unit

4) Efficiently separating the particles from the transport gas stream and depositing the particles in a container.

In developing the sampler, there were several major constraints or design criteria — these are:

1) Total system volume less than 1.0 cubic foot

2) System weight less than 2 pounds, excluding gas reservoir and supply. This weight restriction was removed during development of the sampler.

3) Use of electrical energy only for actuation of controls

4) Remote controlled, except for leads required for starting and stopping the operation

5) Operation in a pressure range from 10 to 100 millibars and a temperature range of -60 to +40 °C

6) Operation at normal atmospheric pressure by adjustment or component interchange

7) Collection of a sample over a 10-foot radius either horizontal or vertical

8) Sampling rate of at least 1 gram per minute from a dry, sandy surface

9) Adequate primary gas supply for 10 minutes of operation at standard pressure and temperature.

3.1 Surface Traverse of Collection Apparatus

The probability of collecting soil particles with a pneumatic sampler is greater if the sampler has a surface traversing capability since particles may not be found at any one location. In this sampler the traversing capability is provided by the ejection and retrieval subsystem.

3.1.1 Ejection Subsystem Development

The function of the unit is to eject the sampler head and trailing tubing a distance of 10 feet from the main sampler before the actual sampling operation commences. Consideration of the constraints led to the selection of an ejection subsystem utilizing the reaction force generated by two CO_2 cartridges. Tests were conducted on components to determine the required orifice size in the cartridges and an effective technique for storing the transport tubing to enable it to properly unwind from the cone.

Two sizes of CO_2 cartridges were tested to determine the magnitude and duration of the thrust for various orifice sizes. Both cartridges were 3/4 inches in diameter; one was 2-1/2 inches long and contained 8.5 grams of CO_2. The other was 3-1/4 inches long and contained 12.5 grams of CO_2. Test apparatus was built to measure the thrust of the CO_2 cartridges which consisted of a 3/4-inch diameter hole drilled in a wooden block. The block was attached to a spring-type scale for measuring the thrust. A hardened steel needle was mounted on a rod which was spring-loaded for penetrating the cartridge. In the test the wooden block was positioned near a penetrator, and upon release of the penetrator the needle pierced and sealed the cartridge. The wooden block was then removed from the penetrator, and the thrust measured for various sizes of needles. These results are given in Table 1.

Table 1. Thrust Developed by CO_2 Cartridges for Various Orifice Sizes

Orifice Diameter (in.)	Maximum Thrust (lb)	Thrust Duration (12.5-gm size) (sec)	Thrust Duration (8.5-gm size) (sec)
0.015	0.1	10	8
0.024	0.4	6	4
0.029	0.5	5	3
0.035	1.0	4	2.5
0.042	1.3	3	2

It was estimated that the ejection of the sampler head and transport tubing would take approximately 2 to 3 seconds; therefore, a needle which produced an orifice diameter of 0.040 inch was used in subsequent testing of the ejection subsystem.

An ejection subsystem was then built to determine the spring compression needed for the penetrator and a suitable storage system for the transport tube. A wooden mockup of the sampler head was made to accommodate two CO_2 cartridges of either size and this sampler head was attached to 10 feet of 1/2-inch I.D. gum rubber tubing. The two CO_2 cartridges were penetrated simultaneously, and the spring compression was varied until the penetrators pierced the CO_2 cartridges properly.

Several tests were next conducted to determine an effective technique for storing the transport tubing. One technique consisted of storing the transport tubing inside a segment of an aluminum cone, which was 10 inches long with end diameters of 8-1/2 inches and 6-1/2 inches. The sampler head and penetrator were placed in the center of the cone and ejected from the large diameter end of the cone. Repeated tests showed that the transport tubing frequently became entangled with the penetrator mechanism and prevented the sampler head from being ejected a distance of 10 feet.

Another storage technique consisted of wrapping the transport tubing around the outside of the cone with the sampler head and penetrator remaining inside the cone. This technique was a success, and after several tests the following cone was selected for storing the transport tubing:

Length:	10 inches
Diameter of Large End:	6 inches
Diameter of Small End:	3 inches.

3.1.2 Retrieval Subsystem Development

The retrieval subsystem is required to move the sampler head and the attached transport tubing from its initial position of ejection back to the main sampler system. This traverse must be accomplished at a constant rate of 12 inches per minute for a period of 10 minutes. Since the system is continuously sampling during this traverse, the time required for traversing the surface is called the sampling period.

Consideration of factors such as weight, simplicity, reliability, and the constraint of not using electrical energy led to the choice of a constant torque spring as the energy source for the retrieval subsystem. Once the energy source was selected, the development work consisted of selecting an adequate spring and complementary mechanical components which utilized the spring energy to retrieve the sampler head.

Tests were conducted on several springs for determining their pertinent operating characteristics as related to the retrieval subsystem. The results are given in Table 2.

Table 2. Operating Characteristics of Springs

Spring Number	Weight (oz)	Input Torque (in. -lb)	Output Torque (in. -lb)	Speed of Tubing (in./min)	Pull of Tubing (lb)
1	22.0	10.0	9.0	16.5	9.0
2	8.0	4.5	4.0	14.5	4.0
3	10.5	6.5	6.0	15.5	6.0
4	6.8	2.5	2.2	12.5	2.2

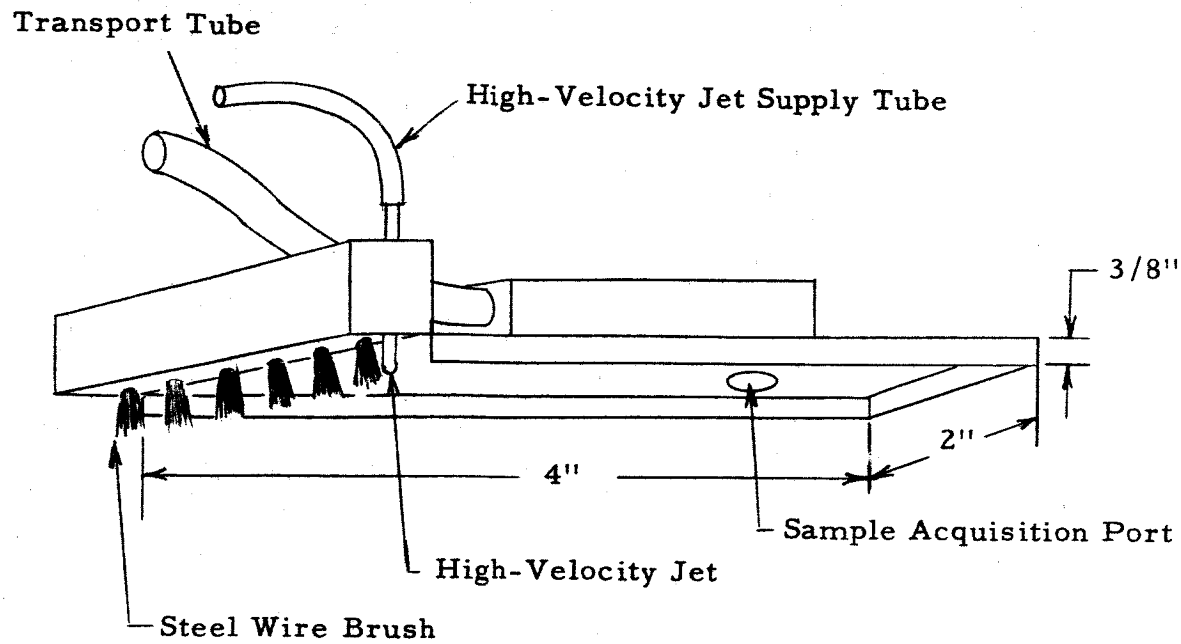
Tests showed that a pull of 5 to 6 pounds on the sampler head and transport tubing was sufficient to traverse surfaces such as those covered with large rocks or tall grass. As a result of these tests, spring number 3 was selected for the retrieval subsystem.

3.2 Soil Aerosolization

Soil aerosolization is an important part of a pneumatic sampler, since the particulate matter must be fluidized to be collected and transported, i.e., the soil particulates must be dislodged from the surface and made airborne near the sample acquisition port. Studies were conducted in the first phase of this program to determine the requirements and the effectiveness of various techniques for aerosolization of diverse soils and rock formations, and the more relevant aspects of this work are presented here.

To determine the effect of high-velocity jets and mechanical agitation on fluidizing particulates, two aerosolizing units were built and evaluated. A schematic diagram of these units is presented in Figure 13.

Tests were conducted on the aerosolizing unit employing the stationary brush for determining the effect on collection efficiency of: 1) the distance between the sample acquisition port and the surface, and 2) the size of the cross-sectional area which is normal to the ambient gas flow and formed by the sampler head and the surface. The distance was varied from 7/32 to 1-3/4 inches. The results showed that a distance of 7/32 inch coupled with a cross-sectional area which was approximately equal to the area of the sample acquisition port produced the highest concentration of particles in the transport tube. This result was observed for all operating conditions under which tests were conducted. The explanation for this result is as follows:



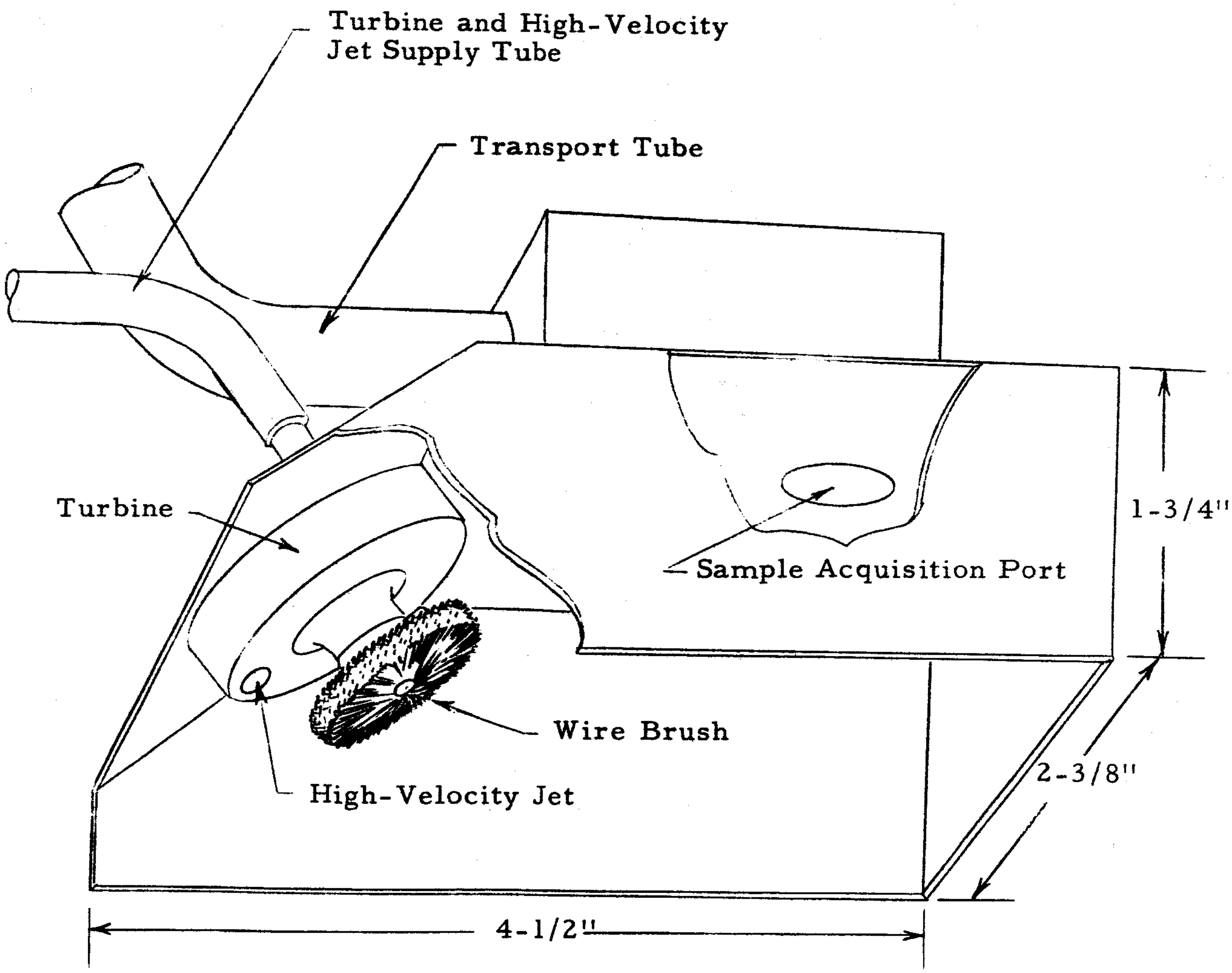


Figure 13. Two Types of Aerosolizing Units

1) The gas velocity under the sampler head must be sufficiently high so that the direct pressure of the gas stream can carry the particles into the transport tube — any velocity greater than this value would not significantly improve the collection efficiency.

2) The distance from the surface to the sample acquisition port must be sufficiently small so that the particles can be carried into the sampler head before gravitational forces cause the particles to settle out of the gas stream.

The aerosolization unit containing the small rotary brush driven by an air turbine was mounted in a bottomless aluminum box as shown in Figure 13. The effluent air from the turbine was used as the high-velocity jet. The wire brush is removable from the turbine. For this unit various types of soil were tested in a chamber maintained at a pressure of 5 millibars. The tests consisted of moving the aerosolizing unit across a soil surface at a rate of 15 feet per minute for a period of 1 minute. The collected material was weighed upon completion of the test. The sequence of tests conducted on each soil were as follows:

Test	Description
A	Natural soil, use of vacuum only
B	Natural soil, use of vacuum and high-velocity jet
C	Natrual soil, use of vacuum, high-velocity jet and brush
D	Surface blown clean, use of vacuum only
E	Surface blown clean, use of vacuum and high-velocity jet
F	Surface blown clean, use of vacuum, high-velocity jet and brush.

The surfaces selected were relative free of vegetation. Tests D, E, and F were conducted to simulate high-wind action on a surface. No attempt was made to optimize the size and position of the brush or the high-velocity jet, and a flow rate of 4 cfm through the 1/2-inch diameter tube was maintained for all the tests. The data obtained from these tests are presented in Table 3. The soil numbers refer to soils described in the final report.

Table 3. Results of Aerosolization Tests for Various Terrestrial Surfaces (at 5-mb pressure)

Type of Soil	Collection Rate (gm/min) Test A	B	C	D	E	F
#1 Fine Sand	0.06	5.91	9.42	0.05	5.80	9.10
#5 Brown Clay Loam	0.04	0.86	1.04	0.10	0.12	0.13
#6 Silty Clay Loam	0.02	0.29	0.50	0.02	0.09	0.21
#50 Sandstone	0.00	0.01	0.06	0.00	0.01	0.03

Table 3 shows that the samples collected from most of the natural undisturbed surfaces (Tests A, B and C) were moderately increased in size by the use of the mechanical brushing along with the high-velocity jet, as compared with use only of the high-velocity jet. Also, on the surfaces that were blown free of loose soil before testing (Tests D, E and F), the additional use of the brush with the high-velocity jet improved the collection rate. For very loose soils, such as sand, these tests show that the use of only the high-velocity jet is sufficient for obtaining a sample rate of 1 gram per minute.

The results given in Table 3, coupled with the constraints imposed on this sampler, show that use of a vacuum and a high-velocity jet is the best choice for the aerosolizing unit. There are two primary reasons for this choice:

1) The collection rate for a sandy-type soil is not appreciably greater when the brush is employed.

2) The brush would require additional power in terms of storage gas which represents additional weight and volume.

3.3 Particle Transport

Pneumatic transport of the soil particles from the Martian surface to the particle separator entails three aspects:

1) An adequate gas flow rate for transporting the particles from the place of sample acquisition to the particle separator unit

2) A pump including its power to sustain the gas flow rate required for particle transport

3) A transport tube which remains sufficiently flexible during the low temperature extremes to insure proper operation of the retrieval subsystem.

These aspects are discussed in detail in the final report and, consequently, only a condensation of the more pertinent points are given here.

3.3.1 Investigation of Pneumatic Transport Efficiency

Investigation of the pneumatic transport efficiency required a test apparatus whereby the quantities of particulate matter transported at various ambient pressures could be accurately measured. For this purpose an aerosolizing-transport-collection apparatus was constructed as shown in Figure 14.

The aerosolizer section consisted of a vibratory feeder for feeding particles directly into the transport tube inlet at a controlled rate. At the feeder discharge end, a high-velocity jet from a small nozzle aerosolized the particles. The combination of the air jet and vibration feeder produced excellent aerosolization (essentially complete breakup

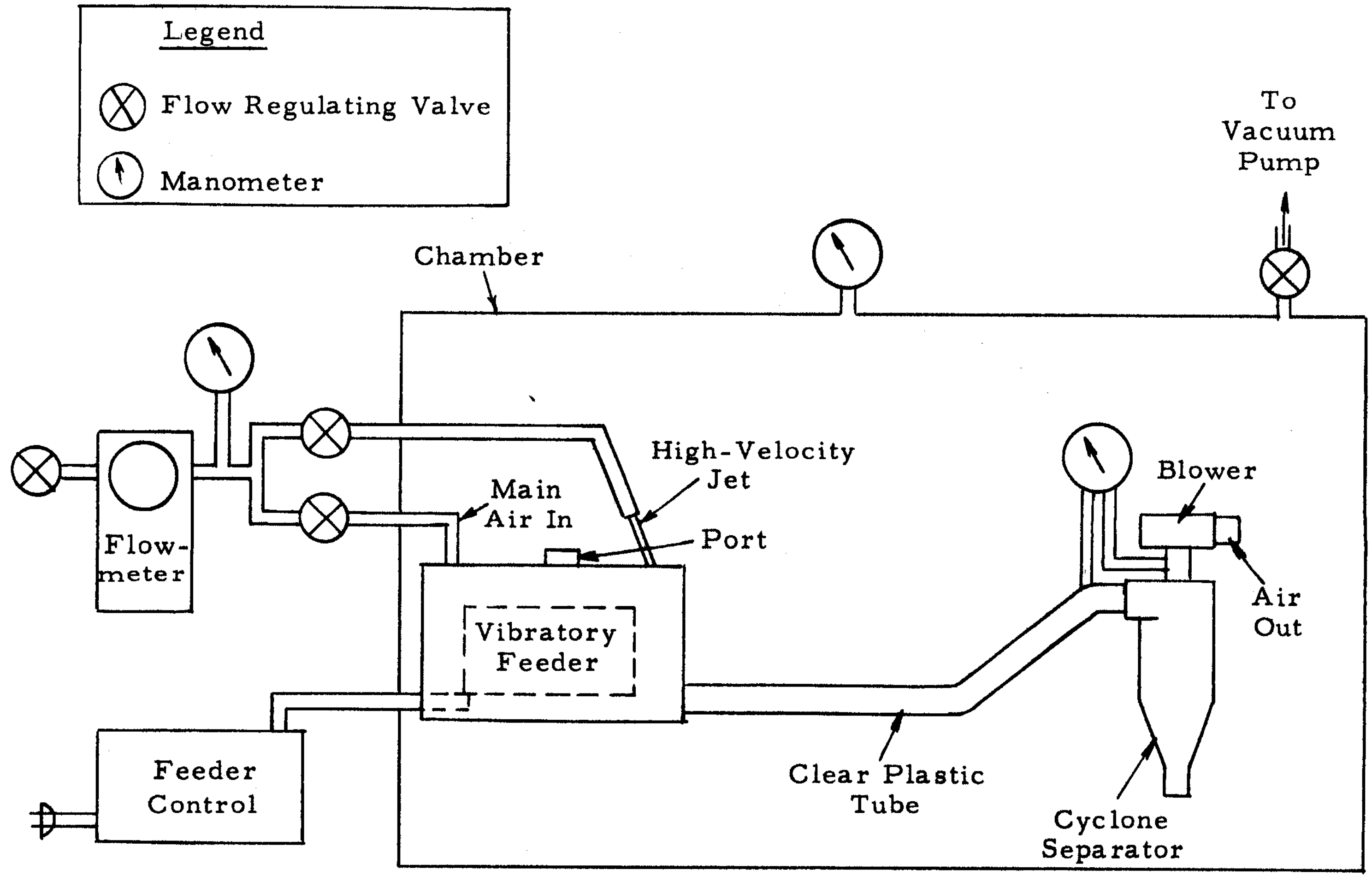


Figure 14. Schematic Diagram of Particle Transport Test Apparatus

of the feed particulate material). This apparatus was mounted in a clear plastic box which was then sealed and positioned inside an environmental chamber. Air was fed into the box, and the flow rate was measured and controlled from outside the chamber. A flexible plastic tube connected the aerosolizer section and the cyclone section and served as the particle transport path. The separator section consisted of a high efficiency cyclone separator for collection the transported sample.

Theoretically, pneumatic particle transport should become increasingly difficult with decreasing ambient pressure. For this reason studies were directed toward empirically determining the minimum pressure requirements that must be met to permit satisfactory transport. With these data, the efficiency and operational envelope for a pneumatic sampler could be established.

Transport tests were conducted for diverse soils at various test conditions. The results presented here are primarily the results of the low pressure tests. All the data given in this section were obtained under the following test conditions:

1) Constants

   a) particulate feed rate
   b) high-velocity jet operation (position and airflow)
   c) transport tube (3/4-inch diameter tube, 5 feet long)
   d) inlet and outlet of transport tube (cyclone inlet positioned 4 inches above the feeder outlet).

2) Variables

   a) particle diameter (62 to 290 microns)
   b) airflow rate (1 to 15 cfm)
   c) soil particles (density 2.2 gm/cc to 2.6 gm/cc)
   d) test chamber pressure (5 to 970 millibars).

Tests were conducted on three different soils: fine sand (soil #1), brown clay loam (soil #5), and silty clay loam (soil #6). The density of the three soils is as follows:

Fine Sand	2.6 gm/cc
Brown Clay Loam	2.5 gm/cc
Silty Clay Loam	2.2 gm/cc.

The soil transport data obtained for soils having an average particle diameter of 100 microns and at a pressure of 5 millibars is given in Figure 15. This figure shows that complete transport of 100-micron particles is obtained at a pressure of 5 millibars with a velocity of 3000 feet per minute. For a 1/2-inch diameter tube, a transport efficiency of 100 percent would require a flow rate of approximately 4 cfm.

As a summary of the horizontal transport phenomenon, the transition range for brown clay loam as a function of ambient pressure and air velocity is presented in Figure 16. These data are given for an average particle size of 100 microns.

Theoretically, the vertical movement of particles in an airstream can be determined from Stokes' law. However, such effects as wall boundary layers are not easily accounted for by theory and, therefore, an experimental investigation was made to determine the important aspects of vertical particulate transport by penumatic techniques. The test apparatus consisted of an aerosolizer, a transport tube and a collector from which it was possible to visually determine the vertical transport efficiency. The test apparatus is shown in Figure 17.

The aerosolizer section was simply a glass jar fitted with a rubber stopper through which was inserted a small tube to serve as the aerosolizer and input air flow, and a 1/2-inch glass tube which serves as the aerosol transport tube. The jar was partially filled with spherical glass beads with the high-velocity jet placed directly over the beads.

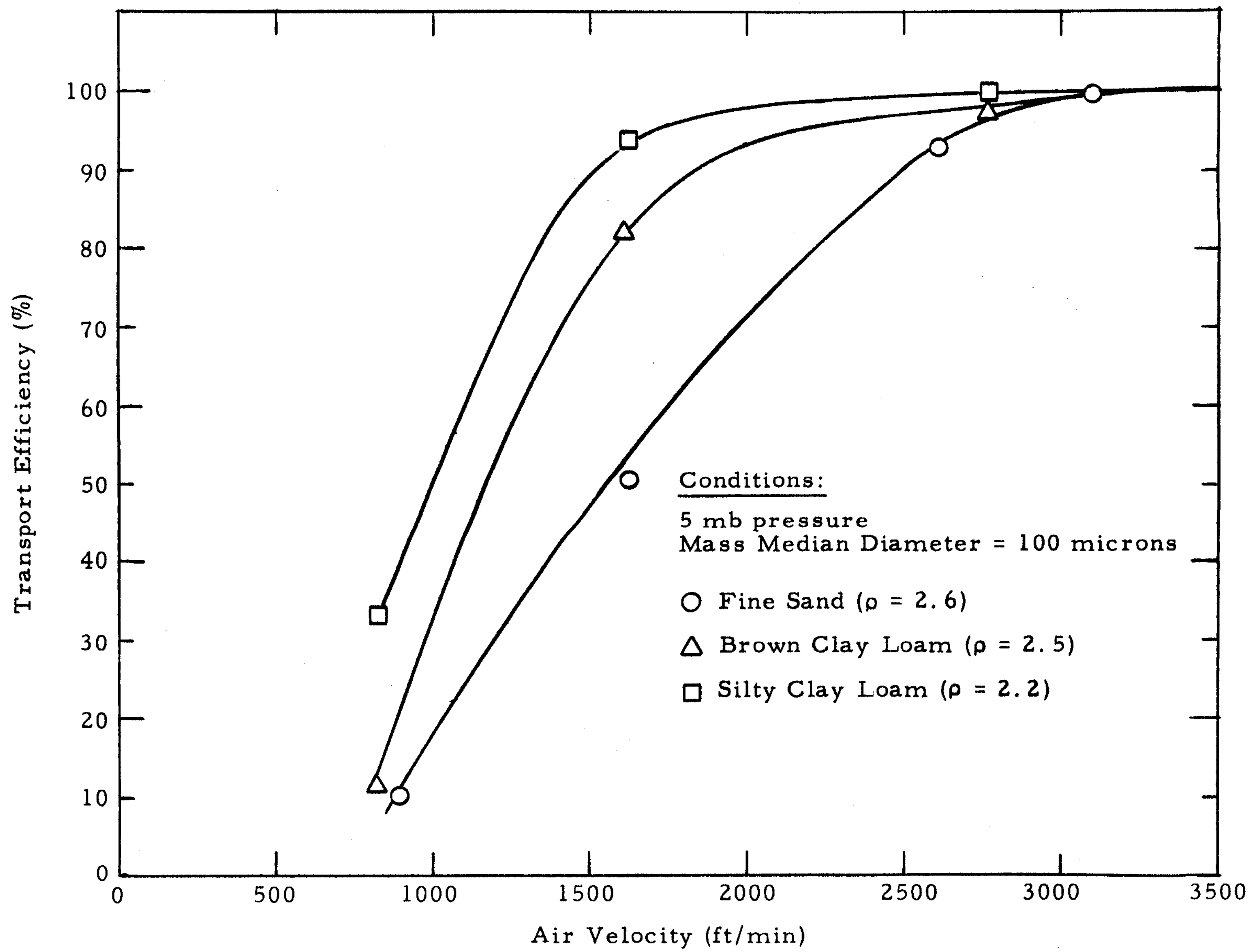


Figure 15. Horizontal Transport Efficiency for Various Types of Soil

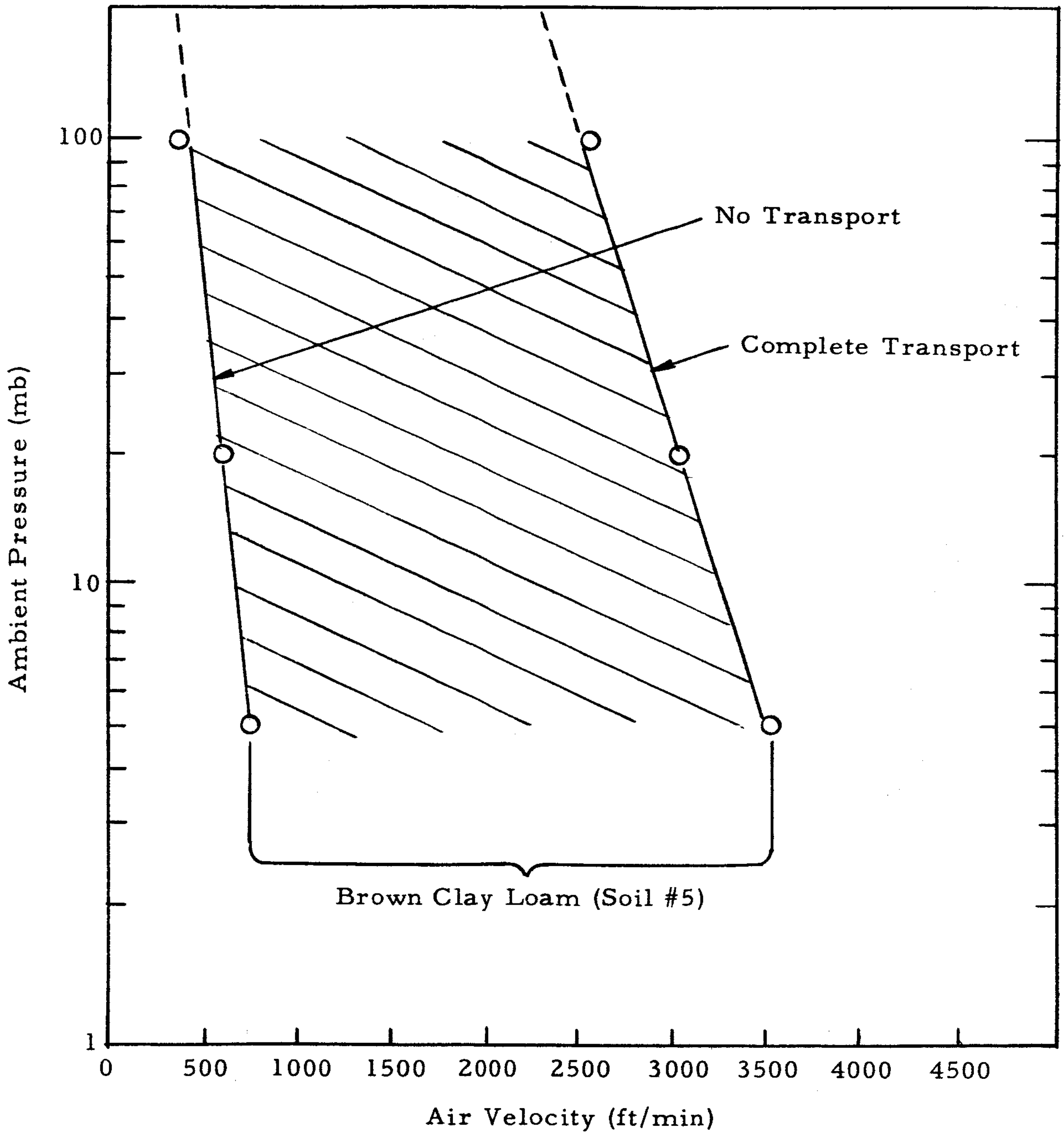


Figure 16. Air Velocity-Ambient Pressure Relationship for Horizontal Transport of 100-Micron Particles

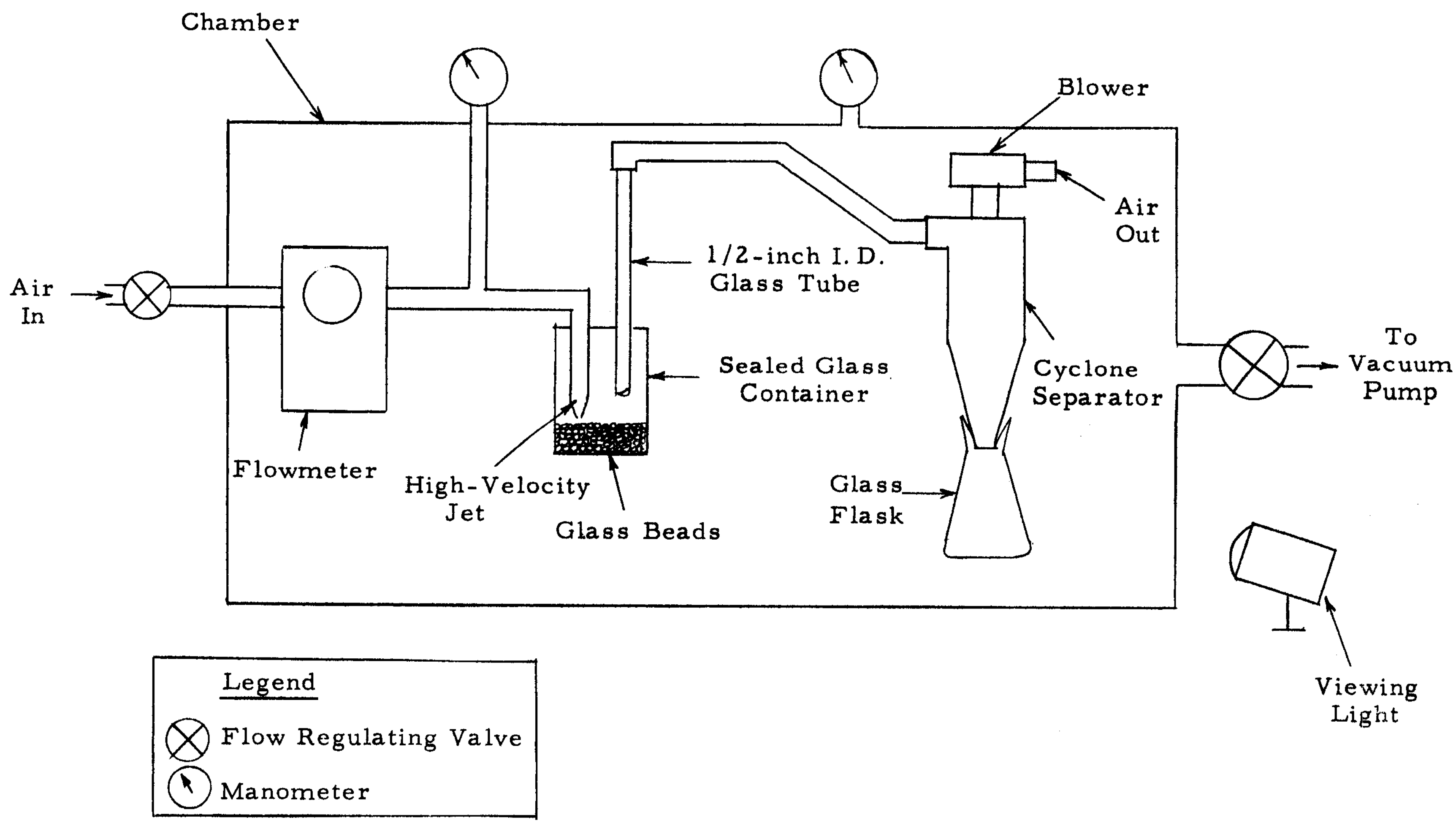


Figure 17. Schematic Diagram of Vertical Transport Test Apparatus

The input air flow was controlled by a flow-regulating valve on the outside of the chamber. A flowmeter was placed in the chamber between the regulating valve and the high-velocity jet. Since the object of the vertical transport tests was to compare vertical transport with horizontal transport, 100-micron glass beads were chosen as the test particles because of the ease of controlling particle size and shape.

The velocity range for complete particle transport was determined by slowly increasing the air flow rate until all of the particles were transported up the vertical tube and collected by the cyclone separator. Any velocity greater than this value would provide complete vertical transport. The air flow rate was then reduced slowly until the collection decreased to zero, which was called the threshold air velocity for the start of vertical transport. It was observed during these tests that if the air velocity was not sufficiently high, the particles dropped down the tube wall toward the inlet or were reentrained when they drifted outward toward the tube center. In contrast, for horizontal transport the particles would simply settle out in the transport tube if the air velocity was not great enough.

The data obtained from these tests are plotted in Figure 18, which shows the entire transition from no transport to complete transport over the pressure range from 5 to 100 millibars. The horizontal transition range is plotted on the same graph. Figure 18 shows that for this pressure range vertical transition occurs at a lower air velocity than horizontal transition. Although there is some overlapping of the ranges at the higher ambient pressure, it can be concluded that horizontal transport is the most important consideration for pneumatic particulate transport. The explanation for this conclusion is that particle settling in the horizontal tube is the limiting factor in pneumatic transport.

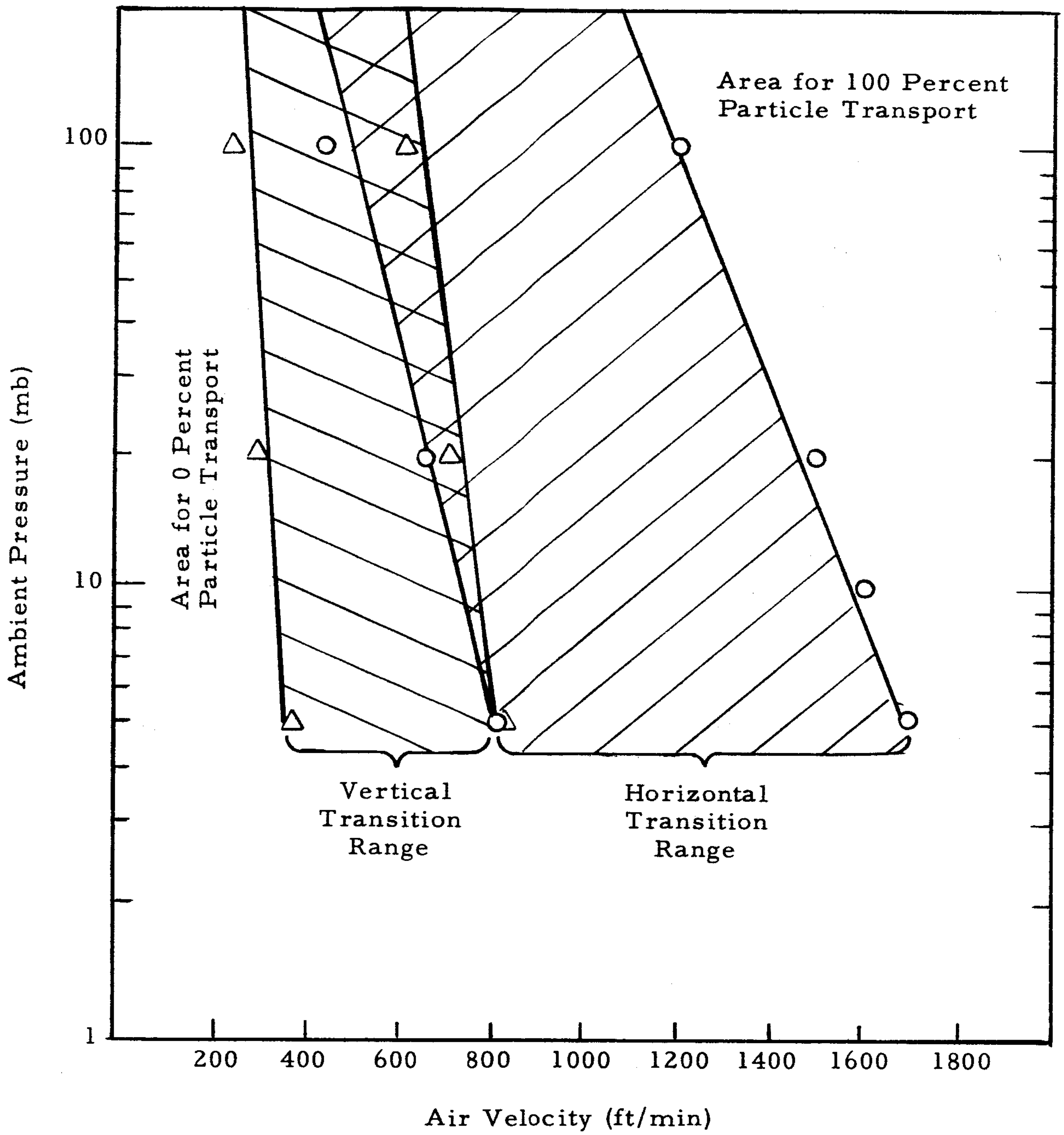


Figure 18. Air Velocity-Ambient Pressure Relationship for Transport of 100-Micron Glass Beads

3.3.2 Air Ejector Development

The second aspect of particle transport to be considered is the type of pump employed in the sampler system. In any pneumatic transport device an adequate gas mover is a prime requisite for satisfactory operation. Previous work done by the Applied Science Division in the field of high-altitude air sampling indicated that the use of an air ejector might be feasible for Martian sampling.[2] In a sample acquisition system utilizing an air ejector, the ejector would replace the motor-blower, and a small tank of compressed gas would replace the conventional power supply required for the blower. The advantages of an air ejector as compared to a motor-blower are as follows:

1) Increased Reliability. The only moving part is a valve. Problems associated with wearing or binding of parts are greatly reduced.

2) Lighter Weight. An air ejector weighs less than an equivalent motor-blower system.

Basically, the operating principle of the air ejector is simple. A high-velocity jet of primary air is injected into a mixing tube from a nozzle. This primary jet, on expanding, entrains the surrounding secondary air and, by a turbulent exchange of momentum, creates a region of low pressure and causes the secondary air to flow.

There are two basic types of air ejectors: a constant pressure mixing system and a constant area mixing system. The constant pressure ejector is difficult to design for optimum performance, since it is quite sensitive to changes in primary, secondary, and ambient pressures and flow rates. Accordingly, the constant area air ejector was chosen for this test because of its inherent simplicity and versatility.

Further, in a constant area ejector most of the pressure rise is produced in the constant area section; therefore, the overall performance of the constant-area-air-ejector is not strongly dependent upon the performance of the diffuser section.

A schematic diagram of an air ejector is presented in Figure 19. Performance of an air ejector is often illustrated by plotting the mass augmentation as a function of the back pressure ratio. Mass augmentation is defined as follows:

$$= \frac{p_1 A_1 V_1 + p_2 A_2 V_2}{p_1 A_1 V_1} = \frac{m_1 + m_2}{m_1} \qquad (1)$$

where:

m_1 = primary mass flow rate

m_2 = secondary mass flow rate.

The back pressure ratio is defined as the ratio of the ambient air pressure to the total pressure at the secondary air inlet.

The mass augmentation must be maximized in order to minimize the amount of storage gas required for a given secondary flow volume. For a given flow rate (m) and back pressure, the mass augmentation is affected by:

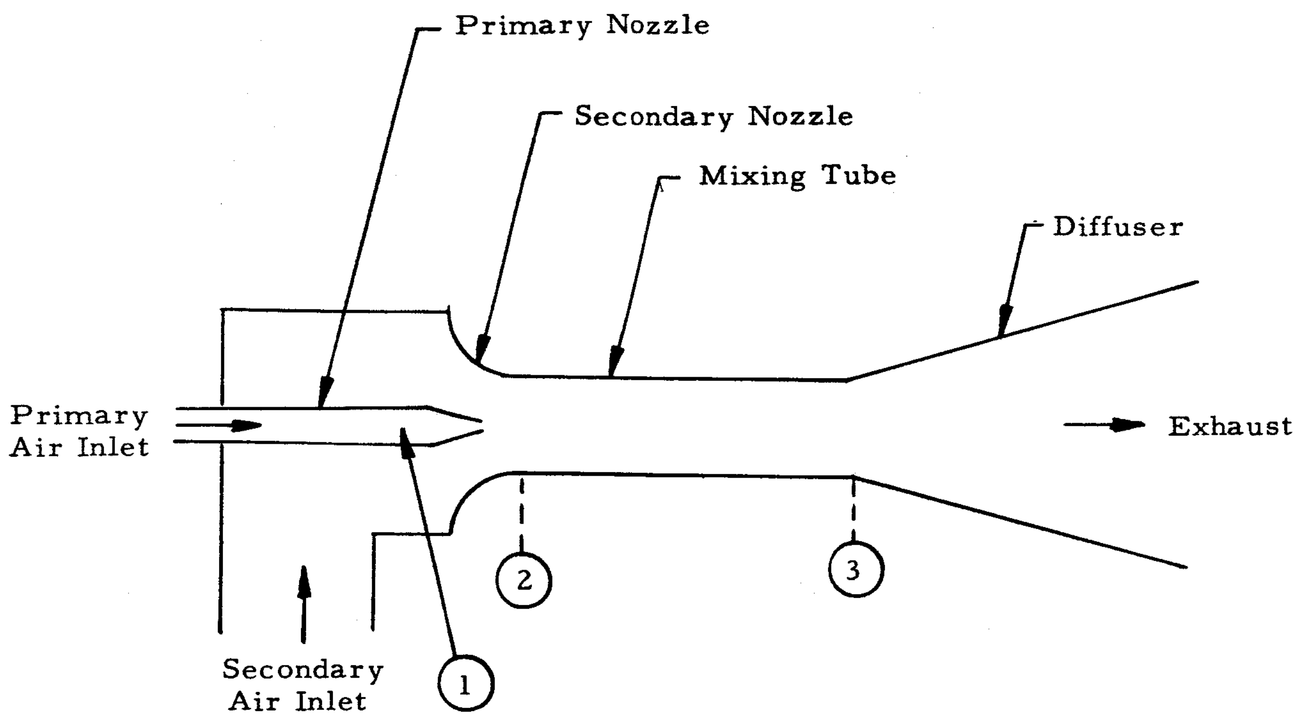
1) Mixing the tube length

2) Ratio of primary nozzle area to the secondary nozzle area

3) Ratio of primary air pressure to ambient air pressure

4) Diffuser length and angle.

Performance tests were run with an air ejector to determine the effect of each of the above parameters. A summary of the results obtained by these tests is given in the subsequent paragraphs and a more detailed discussion of these tests is given in the final report.



Nomenclature

A - area

m - mass flow rate

P - pressure

V - velocity

μ - mass augmentation

ρ - density

a - ambient conditions

1 - conditions at primary nozzle exit

2 - conditions at secondary nozzle exit

3 - conditions at mixing tube outlet

Figure 19. Schematic Diagram of a Constant Area Air Ejector

3.3.2.1 Length of Mixing Tube

A properly designed air ejector should have a mixing tube length of approximately 6 to 9 tube diameters. This range was covered by testing mixing tube lengths of 5, 7 and 10 tube diameters, or 1.5 inch, 2.0 inches, and 3.0 inches, respectively, for a tube diameter of 5/16 (0.312) inch.

Tests were first run without a diffuser to determine if adequate performance could be obtained with the mixing tube alone. It was found that the 2.0-inch long tube performance was better than either the 1.5-inch tube or the 3.0-inch tube. This testing was done for a range of secondary flow rates from 0.4 to 7.0 cfm and back pressure ratios from 1.02 to 1.5. Tests were also run with a 7-degree included-angle diffuser with these same tubes and again test results showed that the tube of 1.5 inch in length gave better performance than the tubes of other lengths.

3.3.2.2 Ratio of Primary Nozzle Area to Secondary Nozzle Area

A good ratio of primary nozzle area to secondary nozzle area has been reported to be about 0.01. Tests were run using nozzle area ratios of 0.005, 0.008, 0.015, and 0.028 utilizing nozzle diameters of 0.022, 0.028, and 0.052 inch, respectively, in a mixing tube of 0.312 inch diameter.

For these tests the primary air pressure was varied and the secondary flow rate was maintained at 3 cfm by adjusting a secondary flow regulating valve. The resulting mass augmentations were compared for the various nozzle area ratios and the results showed that at back pressure ratios less than 1.07, a primary to secondary nozzle area ratio of 0.008 was the most efficient. Similar testing with a 7-degree diffuser section added to the mixing tube gave the same results: the primary to secondary nozzle area ratio of 0.008 gave the best performance for the air ejector configurations tested.

3.3.2.3 Ratio of Primary Air Pressure to Ambient Air Pressure

The optimum primary air pressure to ambient air pressure ratio must be determined from the operating conditions of the pneumatic system. Mass augmentation data as a function of the back pressure ratio are presented in Figure 20. This figure shows an operational envelope generated by the primary to ambient pressure ratio curves which defines the mass augmentation obtainable for a given primary to ambient pressure ratio and back pressure ratio. Additional tests showed that the operational envelope curves generated for an ambient pressure range of 10 to 100 millibars are essentially identical with the curves given in Figure 20 for an ambient pressure of 5 millibars. As a consequence, it may be stated that the mass augmentation is relatively independent of the ambient air pressure for these test conditions.

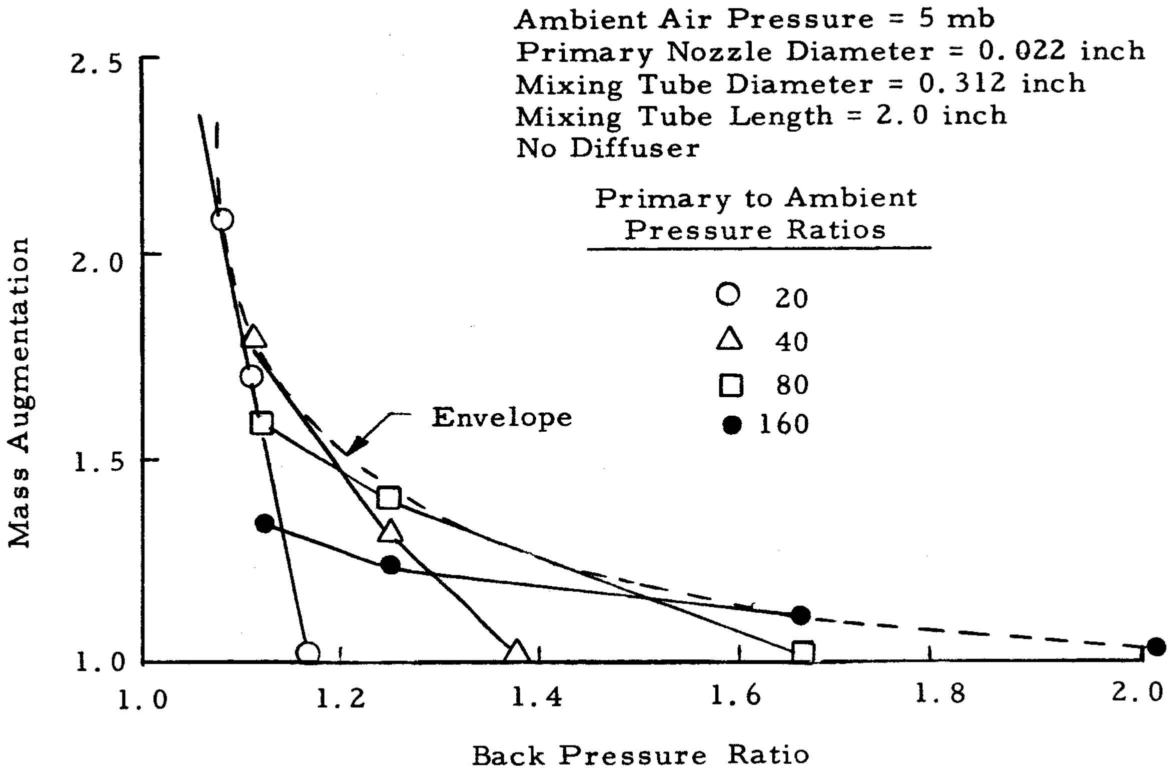


Figure 20. Mass Augmentation as a Function of Back Pressure Ratio

Data showing the secondary air flow rate as a function of the back pressure ratio for an ambient pressure of 5 millibars are given in Figure 21. This figure shows that for a given secondary flow rate an increase in primary to secondary pressure ratio produces an increase in back pressure ratio. However, the efficiency is reduced under these conditions, and as a result a minimum primary pressure ratio was selected which would give an adequate performance over the range of conditions imposed upon the air ejector.

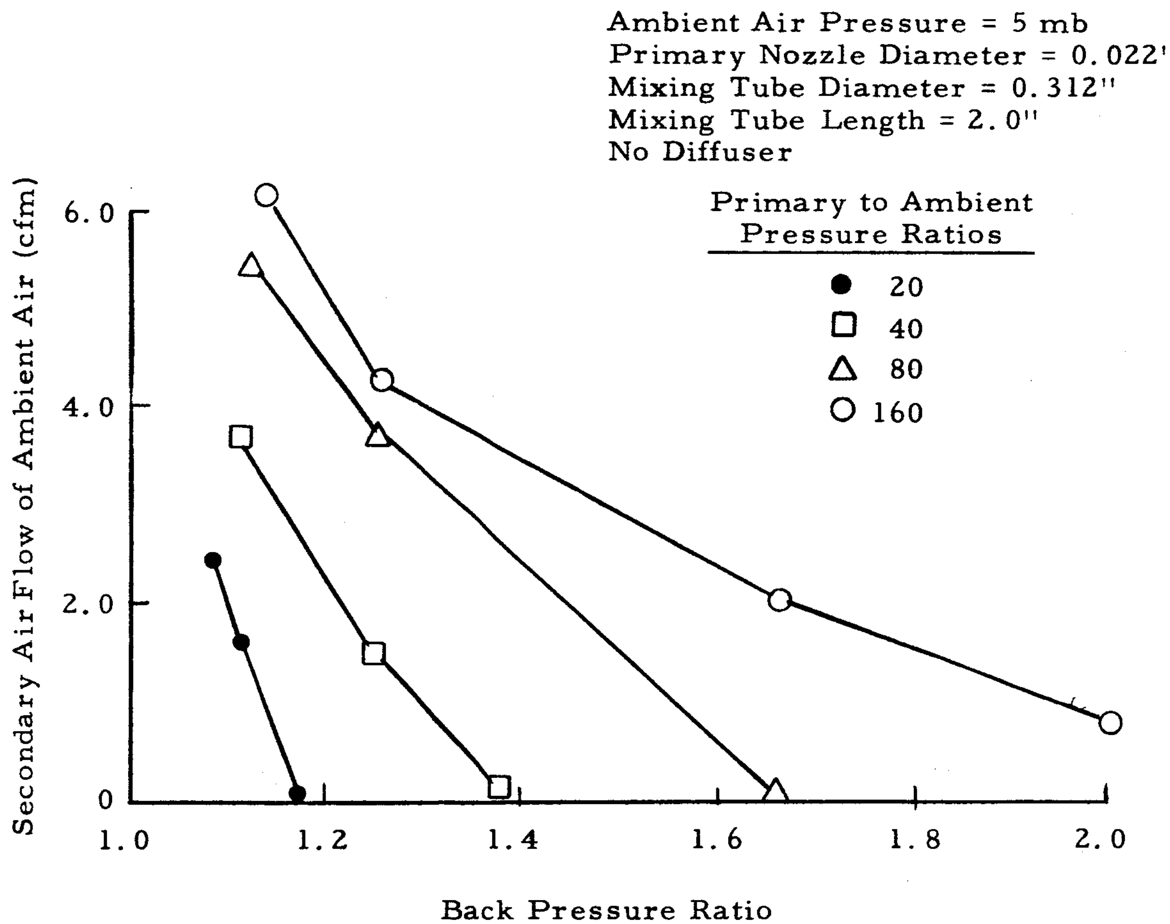


Figure 21. Secondary Air Flow Rate as a Function of Back Pressure Ratio

3.3.2.4 Effect of a Diffuser on Air Ejector Performance

The efficiency of an air ejector pump can be increased by using a diffuser at the outlet of the mixing tube. Two diffusers were made and tested to determine the effect of the diffuser on the performance of the air ejector for various mixing tube lengths.

A diffuser with a 7-degree included-angle and an outlet diameter twice the inlet diameter was used with the 1-1/2-inch, 2-inch, and 3-inch long mixing tubes. For the 2-inch long mixing tube, the diffuser increased the mass augmentation approximately 20 percent at an ambient pressure of 20 millibars and for a back pressure ratio of 1.15. This test was run with a primary to secondary nozzle area ratio of 0.008 and a primary to ambient pressure ratio of 20. At these same conditions using a 1-1/2-inch long mixing tube, the mass augmentation was increased by about 30 percent. A diffuser with a 14-degree included-angle and an outlet diameter three times the inlet diameter was tested under the same conditions. The results showed that the 7-degree diffuser gave an increase in performance greater than the 14-degree diffuser. Diffuser tests were conducted only for an ambient pressure of 20 millibars; however, if tests were conducted at an ambient pressure of 5 millibars the same general conclusion with respect to diffuser angle could be expected, since this change in ambient pressure should not affect the performance.

3.3.2.5 Optimal Air Ejector Design

To arrive at the optimal air ejector design, it was necessary to establish the pressure drop through the transport part of the system, since this pressure drop determines the head that the air ejector must produce for satisfactory operation.

A cyclone separator was tested to determine the pressure drop over the air flow range of 0.5 to 6 cfm at various ambient air pressures. These data are presented in Figure 22 and shows that for a given flow rate, the pressure drop expressed as a percentage of the ambient air pressure remains reasonably constant.

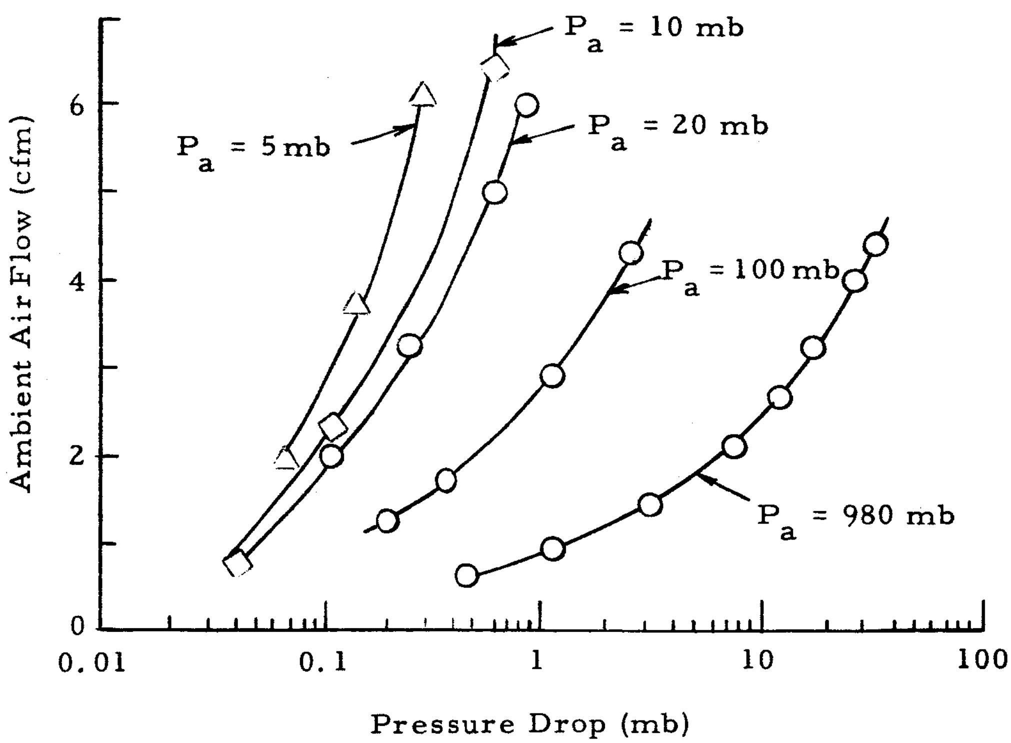


Figure 22. Pressure Drop through a Small Cyclone Separator

Tests were also conducted to determine the pressure drop through small diameter smooth-walled tubes. The inside diameters of the two tubes tested were 1/4 inch and 1/2 inch. Tests were conducted for flow rates up to 4 cfm, which is adequate for complete transport of 100-micron particles. These data are given in Figure 23.

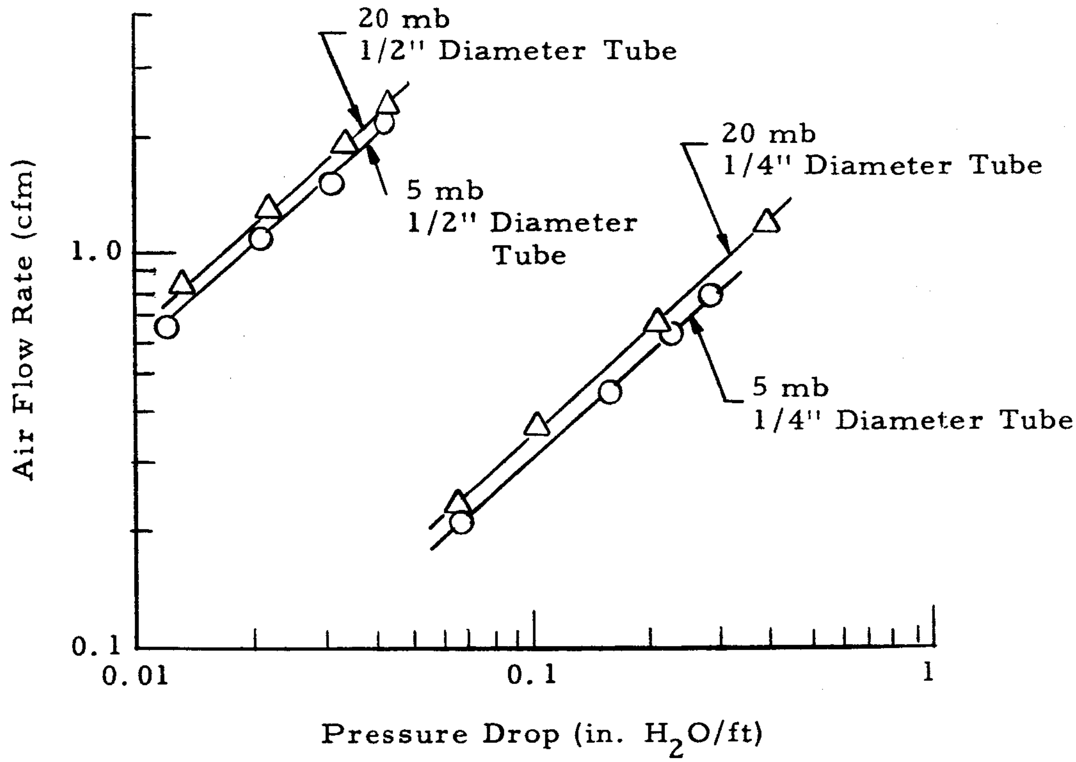


Figure 23. Pressure Drop for Smooth-Walled Tubes

The data on air flow rate-pressure drop given in Figures 22 and 23 were used to predict how the air ejector would operate from the standpoint of overall performance. Using these data it was determined that the pressure drop produced by 10 feet of 1/2-inch I. D. tube and a small cyclone separator was sufficiently small so that the use of an air ejector was feasible.

To determine the operating characteristics of the air ejector, an air ejector was built and its secondary inlet was connected to a cyclone separator connected to 10 feet of 1/2-inch diameter transport tubing. The results of the tests conducted on this system are given in Figures 24 and 25.

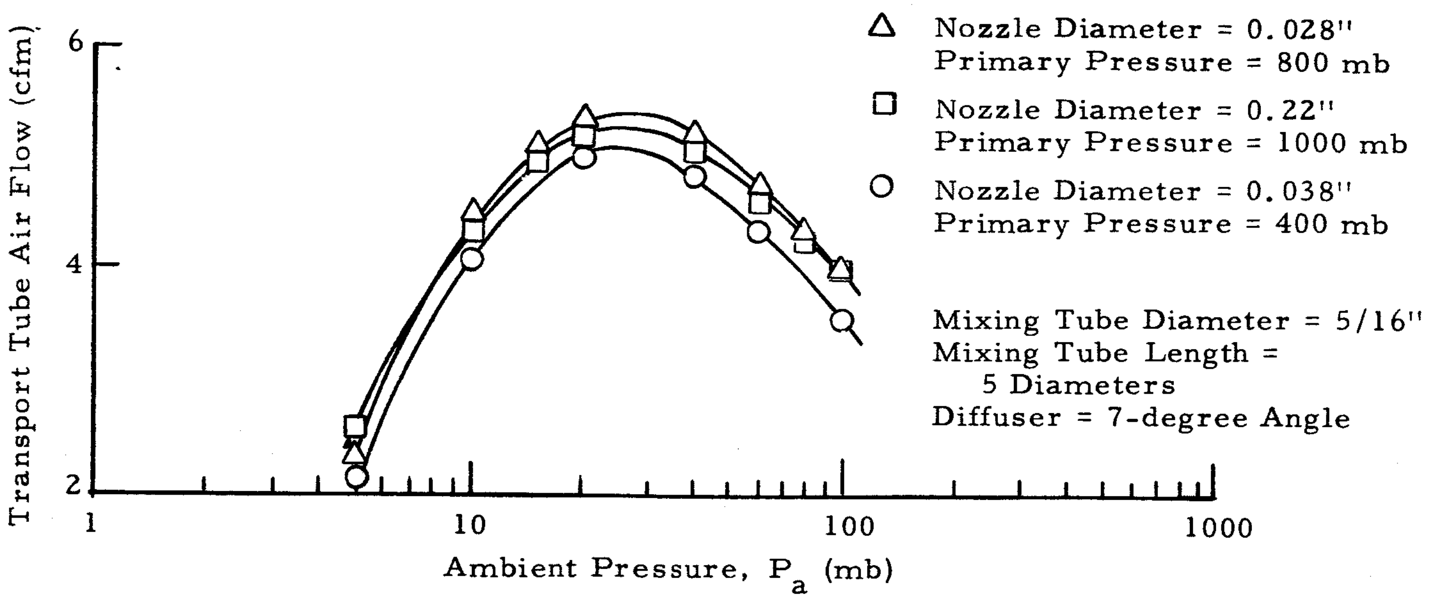


Figure 24. Air Ejector Performance for Various Primary Pressures

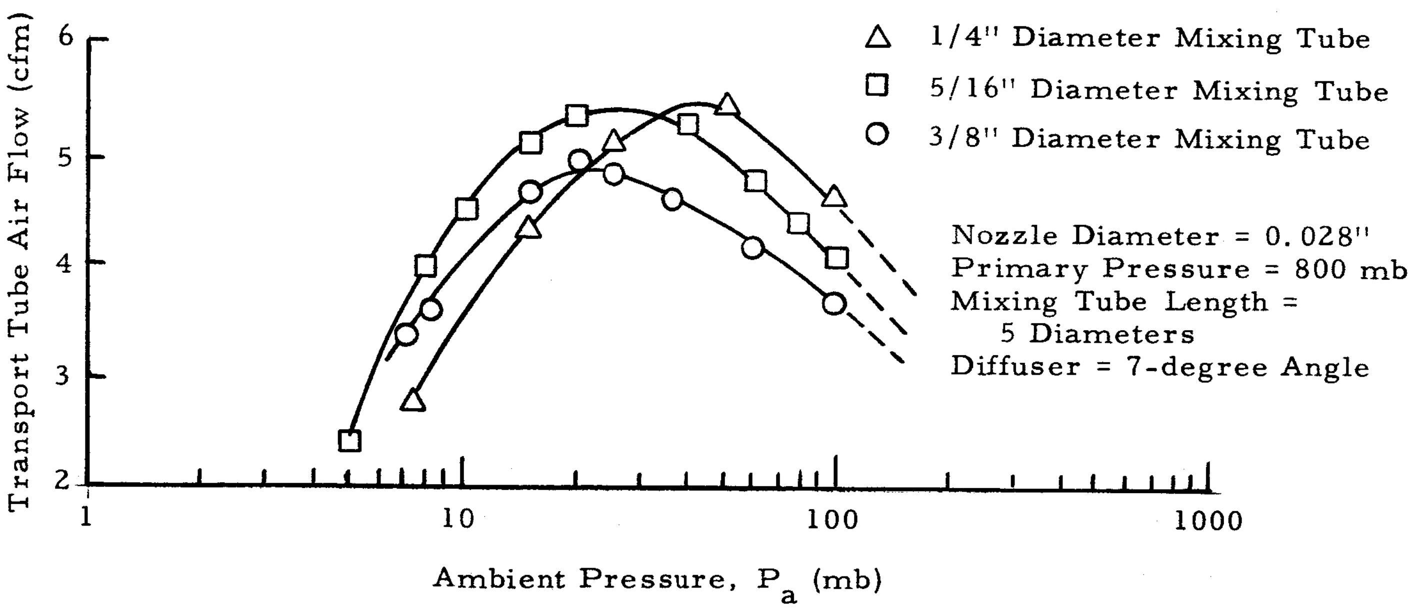


Figure 25. Air Ejector Performance for Various Mixing Tubes

Figure 24 gives the air flow rate through the transport tube as a function of the ambient pressure. The three combinations of nozzle diameters and primary pressures given in Figure 24 give approximately equal primary mass flow rates; consequently, the secondary flow rate, which is the gas flowing through the transport tube, is primarily dependent on the primary mass flow rate. For this system it was possible to transport soil particles at an ambient pressure of 5 millibars with an air flow rate of approximately 2.5 cfm.

This system was also used to determine the effect of mixing tube diameter on the performance. Figure 25 presents the performance data obtained for mixing tubes of three diameters: 1/4-inch, 5/16-inch and 3/8-inch. The performance of the 1/2-inch diameter tube is less than the other two tubes for ambient pressures less than 20 millibars; whereas, the performance of the 3/8-inch diameter tube is less than the 5/16-inch diameter tube for all ambient pressures.

From these data the characteristics of the air ejector selected for the sampler system are as follows:

Primary Nozzle Diameter	=	0.028 in.
Primary Nozzle Air Pressure	=	800 mb
Mixing Tube Diameter	=	0.312 in.
Mixing Tube Length	=	1.5 in.
Diffuser Length	=	3.0 in.
Diffuser Angle	=	7 degrees.

3.3.3 Transport Tube Development

In Section 3.3.1 it was shown that the pneumatic transport of soil particles having a median diameter of 100 microns required a gas velocity of approximately 3000 feet per minute for complete transport. The diameter of the transport tube was determined by considering the total pressure drop through the tube and its effect on the performance of the air ejector. From the data given in Figure 23, on pressure drop through tubes, and the data given in Figures 24 and 25 on air ejector performance, a tube having an inside diameter of 1/2 inch was selected. This size allows space for a 1/8-inch tubing to be inserted inside the 1/2-inch tube for supplying gas to the high-velocity jets.

Gum rubber tubing used in the preliminary testing of the design concept worked satisfactorily at room temperatures. However, because of the cold temperature requirements a silicone rubber comparable to the gum rubber in hardness was specified for both of the tubes. The silicone rubber specified was Dow-Corning DC 50, which has a Durometer Hardness Shore A Scale of 50 at standard temperature. A local rubber product fabricator was recommended by Dow-Corning and engaged to extrude the tubing from this material. A sample of this material was obtained and tested for determining its low temperature characteristics. These tests were conducted in an environmental test chamber shown schematically in Figure 26. The tubing was wrapped on the manipulator spools in place of the manipulator cord. By this means the tubing could be rolled from one spool to the other and flexed. The results of these tests showed that there was no significant increase in hardness or stiffness at a temperature of -60°C. Gum rubber tubing tested at this temperature showed a significant increase in hardness. Gum rubber tubing definitely would not be suitable for operation at the low temperature.

A fabricator was unable to extrude this material (DC 50) into a tube that was not flat; as a consequence, a similar material (DC 747) with a Durometer Hardness Shore A Scale of 70 was substituted. The tubing made from this material was acceptable except that at temperatures below -30°C it increased in stiffness and became difficult to wrap on the storage cone. The DC 747 material is acceptable for demonstrating feasibility; however, it is recommended that the tubing be made from the DC 50 material for low temperature application.

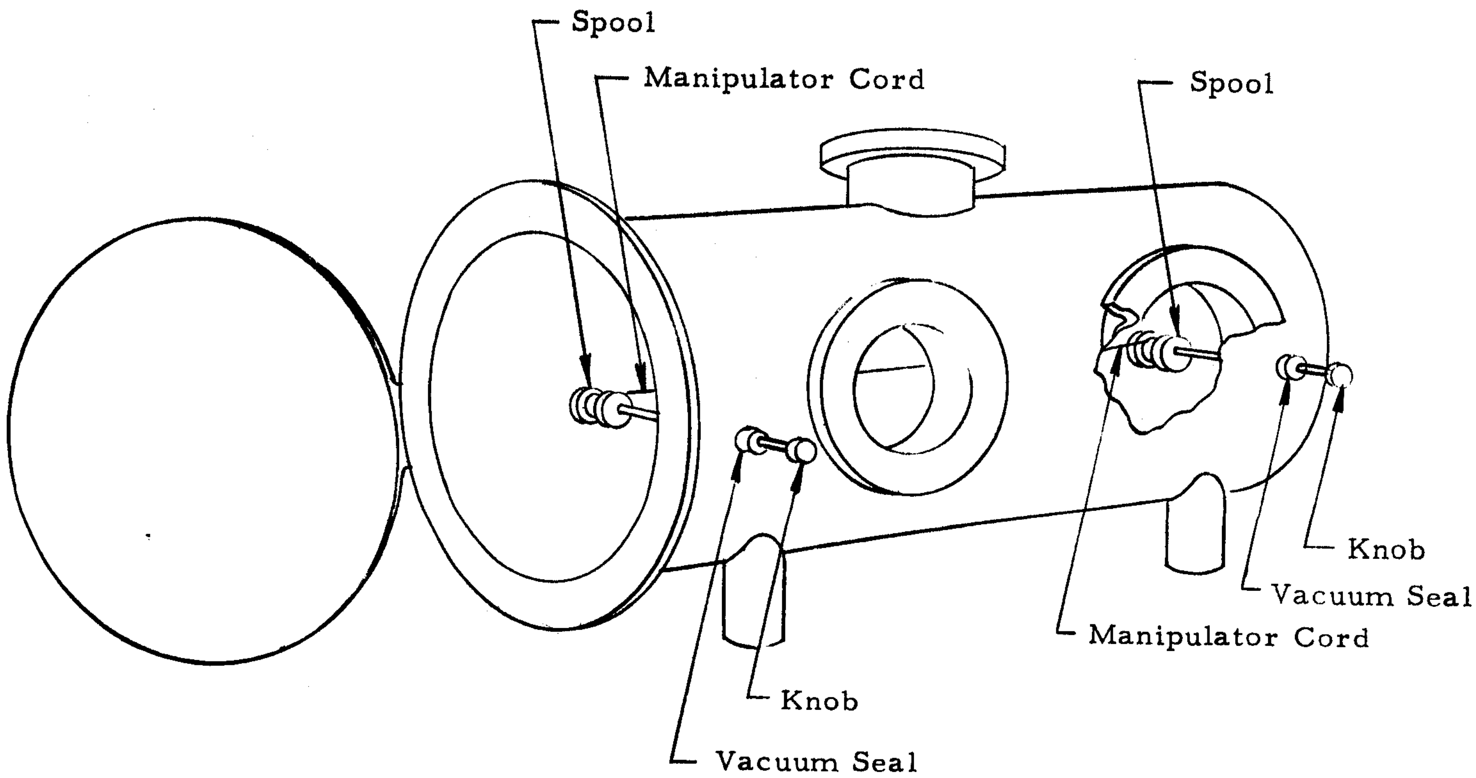


Figure 26. Schematic Diagram of Environmental Test Chamber

3.4 Development of the Cyclone Separator

The cyclone separator is a widely used particle recovery unit because of its simplicity and relatively low resistance to gas flow. Another characteristic of a cyclone separator is that the sample obtained consists only of soil particles which are not mixed with any other material. These characteristics match very well those of the air ejector and the overall requirements for this sampler system; consequently, the cyclone separator was selected as the particle recovery unit for the pneumatic sampler. A detailed discussion of the development of the cyclone separator is given in the final report.

The cyclone separator was originally designed for the outlet tube to be attached to the inlet of the air ejector. In this configuration the air ejector would draw air from the transport tube through the cyclone separator. A schematic diagram of the cyclone separator is given in Figure 27. The collection chamber is a small glass jar which holds approximately 50 grams of fine sand.

During the development of the sampler the feasibility of operating the air ejector-cyclone separator such that the air ejector would pump into the cyclone separator and thereby pressurize the collection chamber was investigated. This configuration would permit the soil sample to be transferred from the collection chamber to the detection unit by utilizing this pressure. To determine if this configuration was feasible, tests were conducted on the air ejector-cyclone separator for both the conventional drawthrough configuration and for the proposed configuration of the air ejector pumping into the cyclone separator. These tests were performed at atmospheric pressure. The two configurations of the air ejector-cyclone separator are shown schematically in Figure 28. The tests consisted of the following:

1) Measuring the pressure in the collection chamber

2) Determining the effect of the depth of the outlet tube on the pressure in the collection chamber

3) Measuring the mass augmentation.

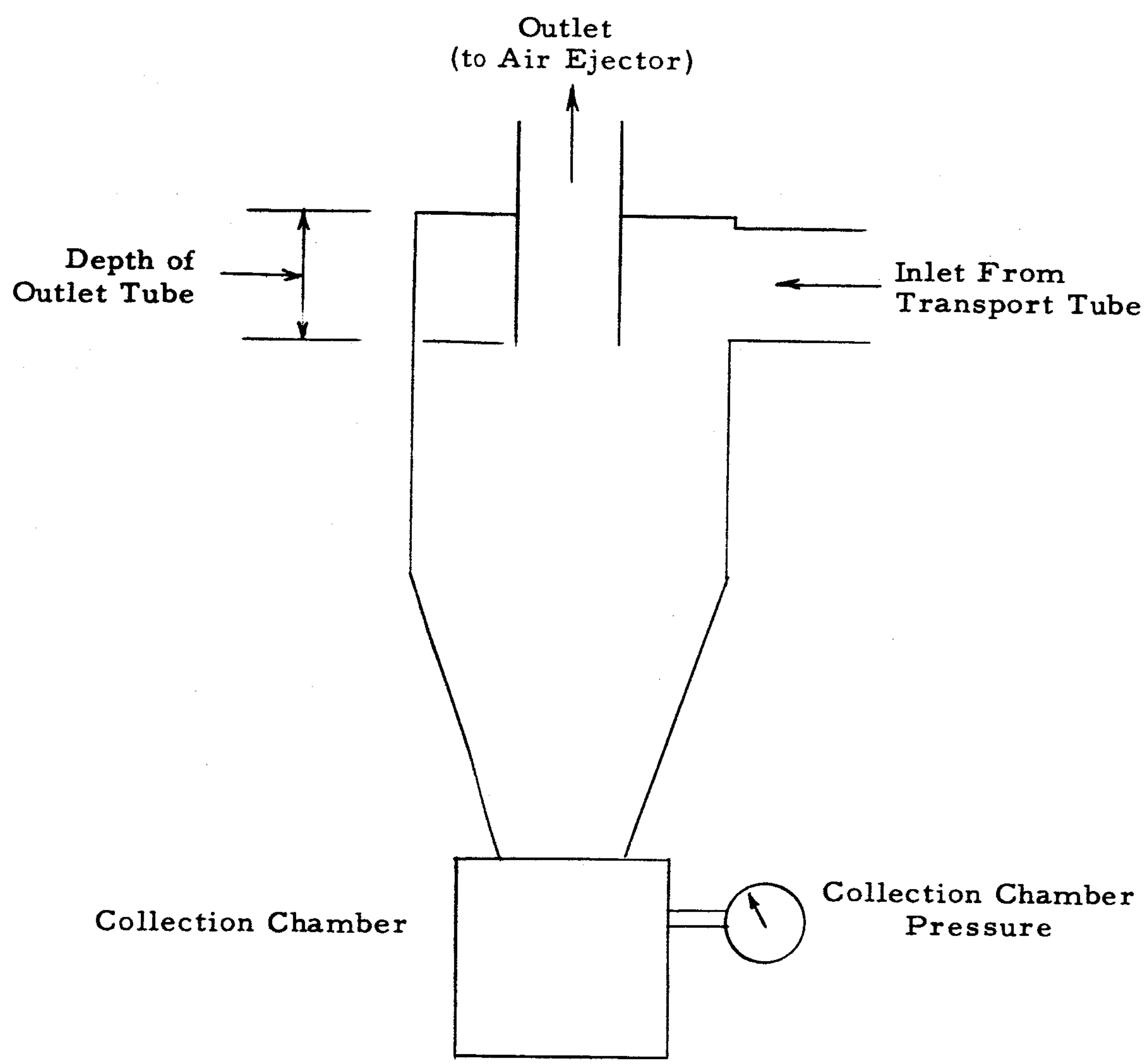
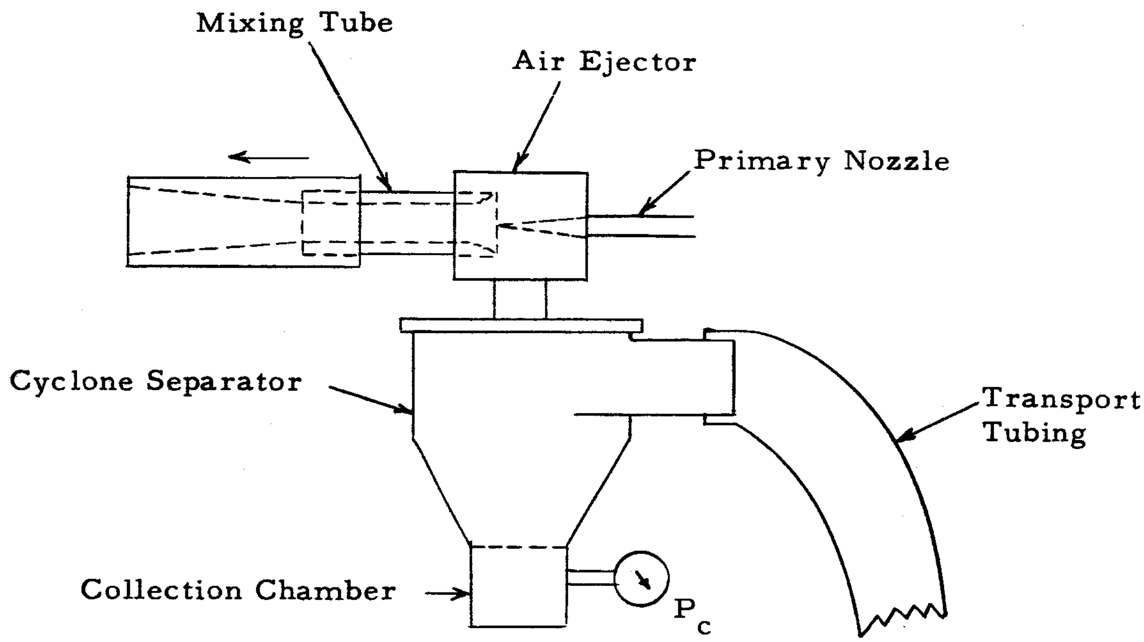
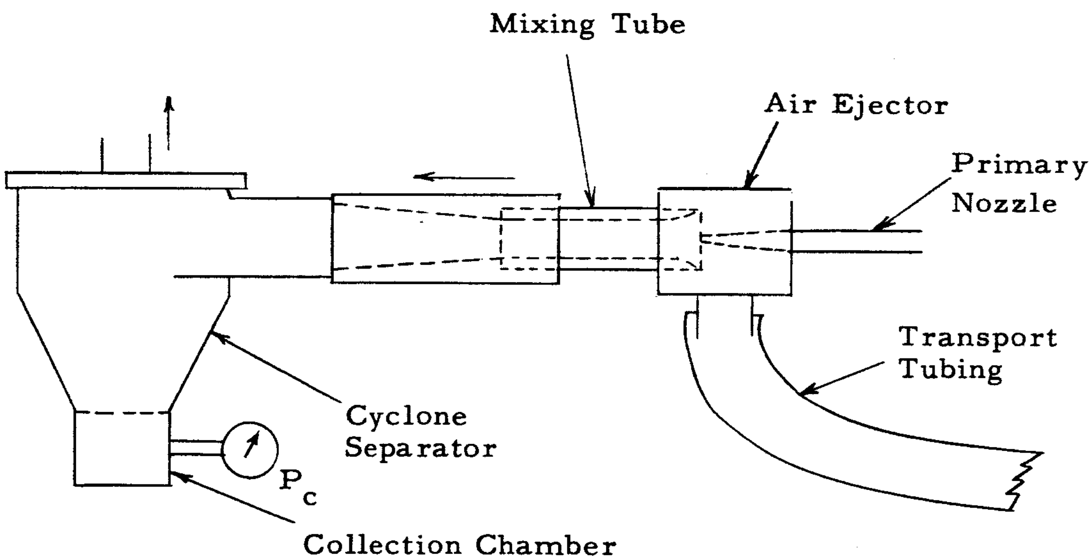


Figure 27. Schematic Diagram of Cyclone Separator



Air Ejector Pumping Air From the Cyclone Separator



Air Ejector Pumping Air Into the Cyclone Separator

Figure 28. Possible Air Ejector-Cyclone Separator Configurations

The pressure in the collection chamber was measured with a liquid manometer. For the air ejector pumping air from the cyclone separator, the collection chamber pressure was 9 and 20 inches of water below atmospheric pressure for secondary air flow rates of 3 and 4 cfm, respectively. When the air ejector pumped into the cyclone separator, the pressure in the collection chamber remained somewhat negative with respect to atmospheric pressure. This negative pressure results from the vortex pattern in the cyclone separator. It should be noted that for the air ejector pumping into the cyclone separator, the air flow rate through the cyclone separator has been increased, since both the primary and secondary air flow through the cyclone separator. As a result the cyclone separator is probably somewhat undersized for this air flow rate.

Tests were performed to determine the effect of the depth of the outlet tube in the cyclone separator on the pressure in the collection chamber. Both configurations of the air ejector-cyclone separator were tested and all other parameters were held constant. The depth of the outlet tube was varied from 0 to 1-1/2 inch for a fixed secondary flow rate of 3.8 cfm. The results showed that there was no significant change of pressure in the collection chamber or pressure drop through the cyclone separator for either configuration.

Mass augmentation tests were conducted to determine the effect of each configuration on the overall transport system efficiency; results are given in Figure 29. This figure shows that the mass augmentation is approximately 40 percent less when the air ejector is pumping air through the cyclone separator as compared to when the air ejector is pumping air from the cyclone separator. Consequently, a larger quantity of primary gas would be required to operate the sampler for the configuration where the air ejector pumps into the cyclone separator.

In conclusion, the results of the above tests show that having the air ejector pump air from the cyclone separator is the better of the two configurations. However, it should be noted that these tests were

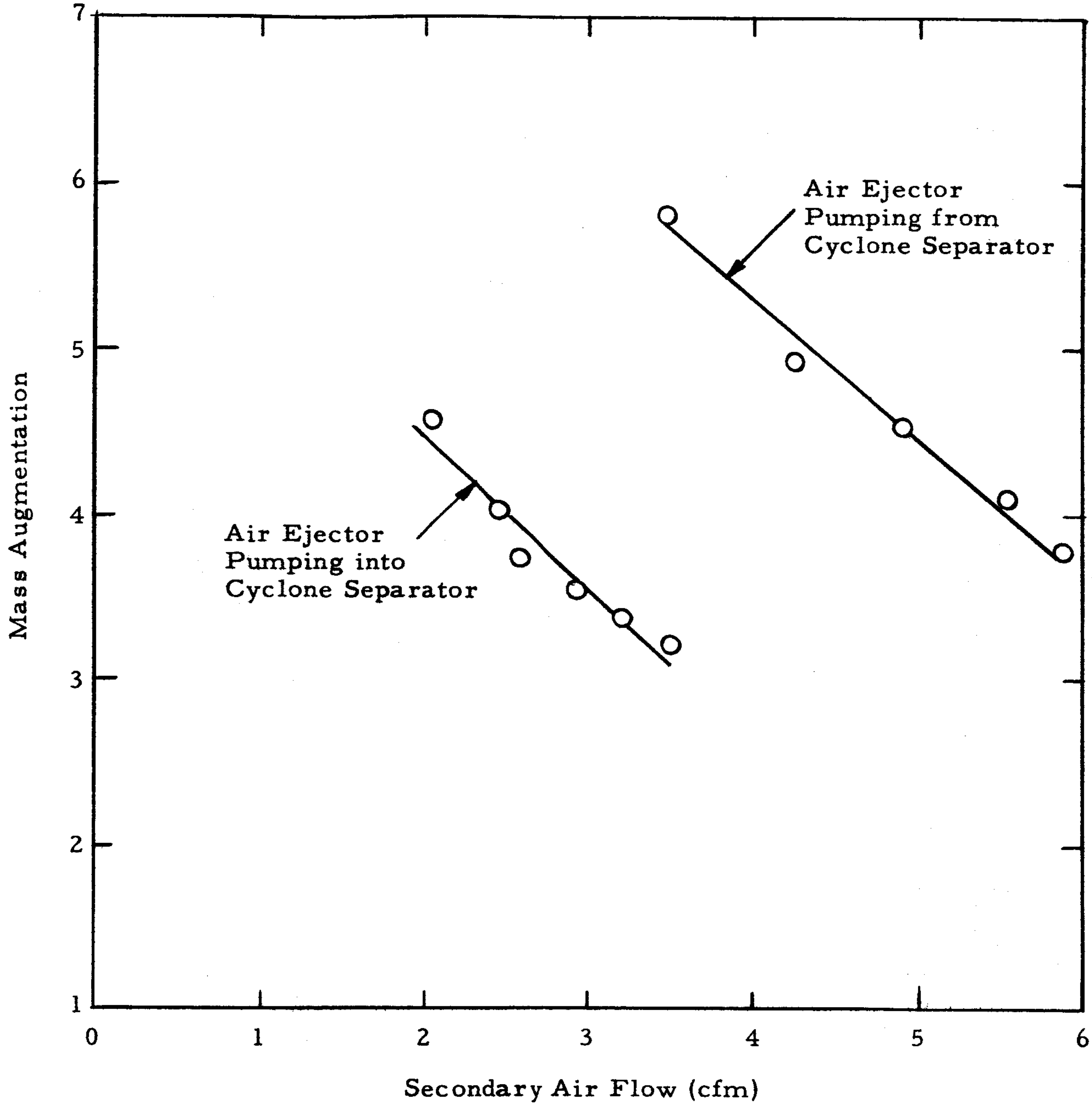


Figure 29. Mass Augmentation for Two Configurations of the Air Ejector-Cyclone Separator

conducted with a cyclone separator designed for a smaller flow rate than that flowing through the cyclone separator for the air ejector pumping into the cyclone separator. A new design and adequate development might show that the configuration employing the air ejector pumping into the cyclone separator is feasible. For example, a simplified analysis of the back pressure ratios for the two configurations shows that the air ejector pumping into the cyclone separator would have the lowest back pressure ratio provided the pressure drop through the transport tube and cyclone separator are constant and equal. The back pressure ratios are given by the following expressions:

$$\Phi_1 = \frac{P_a}{P_a - 2(\Delta P)} , \tag{2}$$

$$\Phi_2 = \frac{P_a + \Delta P}{P_a - \Delta P} , \tag{3}$$

where:

Φ = back pressure ratio

ΔP = pressure drop through cyclone separator or transport tube

P_a = atmospheric pressure

subscript 1 = air ejector pumping from the cyclone separator

subscript 2 = air ejector pumping into the cyclone separator.

A comparison of Equations (2) and (3) shows that $\Phi_1 > \Phi_2$ for any $\Delta P > 0$, which means that the back pressure ratio is always less for the configuration where the air ejector is pumping into the cyclone separator.

4. SYSTEM TESTING

The testing program for the Pneumatic Surface Sampling System was divided into two areas: sample acquisition tests and biological tests.

4.1 Sample Acquisition Tests

The objective of the sample acquisition tests was to determine for the pneumatic sampler the mass sampling rate and the degree of sample bias with respect to particle size. To accomplish this objective a series of tests was conducted on a dry, sandy surface (soil #1 as described in the final report) at various combinations of temperature and pressure.

The test procedure consisted of activating the pneumatic sampler on or near the sandy surface and then letting the sampler operate in its normal manner. During the operating period the sampler was continuously observed to be certain that all subsystems were functioning properly. Upon completion of a given test or run, the sample deposited in the collection chamber was weighed and a size analysis was made of the sample.

The size analysis was performed in accordance with the National Bureau of Standards Sieving Test. A soil sample was placed on a Tyler shaker for a period of 15 minutes. The sieve sizes used were as follows:

#20 = 841 microns
#70 = 210 microns
#120 = 125 microns
#170 = 88 microns
#230 = 62 microns.

A size analysis of the dry, sandy soil was conducted before any tests were run. This analysis gives the particle size distribution of the sand so that the degree of bias obtained in the sample collected by the pneumatic sampler could be assessed. This size distribution would also be obtained if a classical sampling technique (use of a spatula) were employed. The particle size distribution obtained for the dry, sandy soil is given in Table 4.

Table 4. Particle Size Distribution of the Dry, Sandy Soil (classical sample)

Particle Size Increments (microns)	> 841	210 to 840	125 to 210	88 to 125	62 to 88	< 62
Percent by Weight	0.3	41.6	42.6	8.6	4.2	2.7

The first sampling tests were conducted at room temperature and atmospheric pressure. The air supply to the air ejector and high-velocity jets was maintained at 20 psig for these tests. At these conditions a sample of approximately 20 grams per minute was collected. The size distribution of this sample is given in Table 5.

Table 5. Particle Size Distribution of the Sample Collected at Room Temperature and Atmospheric Pressure

Particle Size Increments (microns)	> 841	210 to 840	125 to 210	88 to 125	62 to 88	< 62
Percent by Weight	0.3	41.4	42.8	9.8	3.9	1.8

The next sampling test was conducted at a pressure of 5 millibars and at room temperature. This test was performed in the environmental test chamber located at the Applied Science Division. The gas to the air ejector and the high-velocity jets was maintained at a pressure of 800 millibars. For this test a sample of approximately 18 grams per minute was collected. The size distribution of this sample is given in Table 6.

Table 6. Particle Size Distribution of the Sample Collected at a 5-Millibar Pressure and Room Temperature

Particle Size Increments (microns)	>841	210 to 840	125 to 210	88 to 125	62 to 88	< 62
Percent by Weight	0.5	41.3	42.8	9.6	4.1	1.7

The next tests were conducted in an environmental test chamber of the American Petrochemical Company in Minneapolis, Minnesota. This chamber is approximately 10 feet in width, 15 feet long and 8 feet high. Dry sand (soil #1) was spread on the floor in this chamber. The gas supply for the air ejector and the high-velocity jets was maintained at a pressure of 800 millibars for all tests conducted in this chamber. The results of the tests conducted in this chamber are given in Table 7.

Table 7. Results of Tests Conducted in the Environmental Test Chamber at American Petrochemical Company

Pressure (millibars)	Temperature (°C)	Collection Rate (grams per minute)
10	Room Temperature	15 to 20
40	Room Temperature	15 to 20
100	Room Temperature	15 to 20
30	-60	15

These tests show the following results:

1) A sampling rate of at least 15 grams per minute is feasible for pressures as low as 5 millibars (Table 6).

2) Particles as large as 800 microns can be successfully transported by the sampler system.

3) The particle size distribution is not significantly biased by the acquisition process.

4) The sampler will collect satisfactorily at temperatures as low as -60°C.

4.2 Biological Tests

The objective of the biological tests was to determine if the samples acquired with the pneumatic sampler are comparable in biological content to a classical soil sample. The tests were conducted on two types of soils: a brown clay loam (soil #5) and a silty clay loam (soil #6). The classical sample was obtained with a spatula, and the sampler was operated in its usual manner to obtain its sample. All samples, obtained at atmospheric pressure and room temperature, were analyzed for biological content by both a turbidimetric technique and plate counts.

The procedure followed for the turbidimetric tests was as follows:

1) Inoculate 1 gram of soil particles into 50 milliliters of nutrient broth.

2) Shake the broth to disperse the soil particles.

3) Centrifuge the solution at 100 g's for a period of 10 minutes.

4) Decant the supernate into a sterile bottle and shake on a reciprocating platform while maintaining the supernate at 35°C.

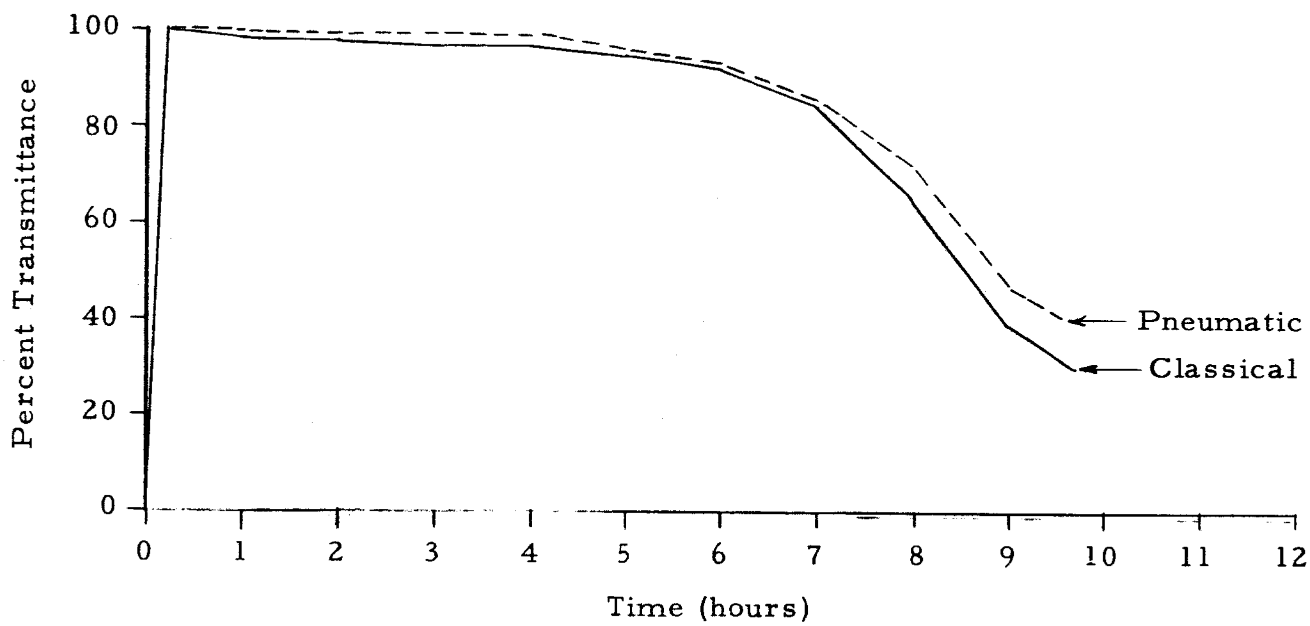
5) At hourly intervals remove 5 milliliters of the supernate from the 100-milliliter bottle and measure the turbidity.

The results of the turbidity tests are given in Figure 30. This figure shows that there is very little difference between the turbidity curves for the samples obtained with the sampler and by the classical method. This figure also shows that the growth was detected for both types of soil at approximately 6 to 8 hours after inoculation. In general, these results are comparable to the results given in the final report.

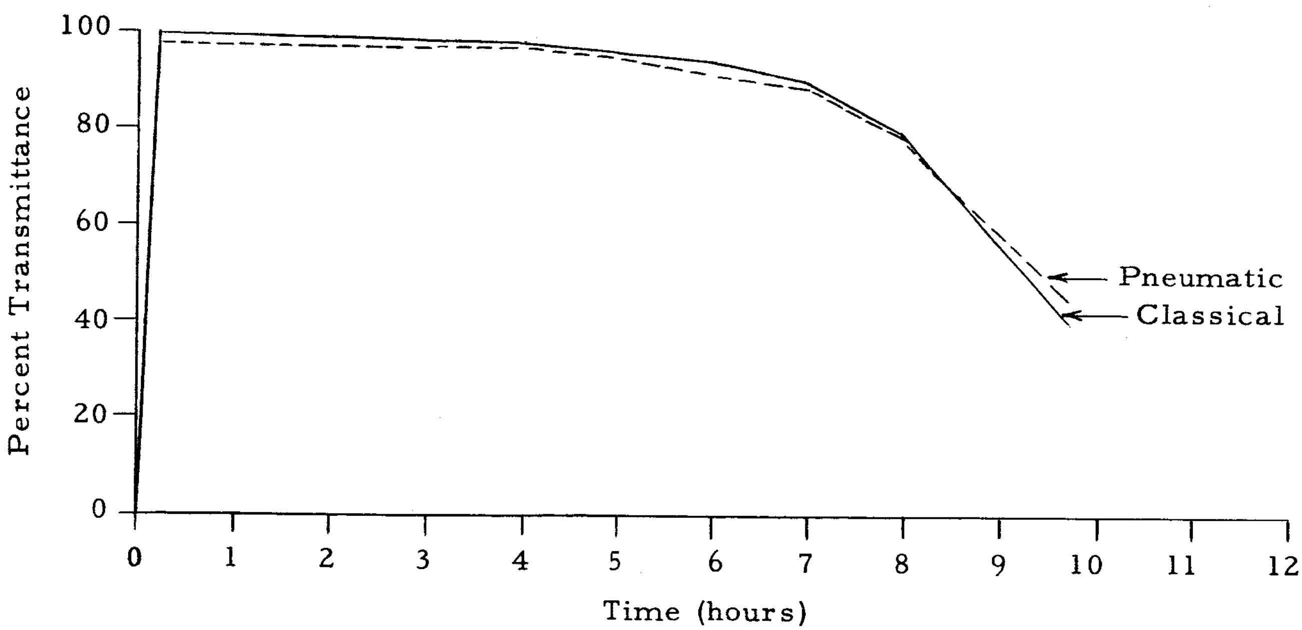
Plate counts were made for the soil samples using aqueous soil suspensions in TGE agar. All of the plates were incubated at 35°C for 24 hours which was followed by several days of incubation at room temperature. The results of these tests are given in Table 8 in terms of viable counts per gram.

Table 8. Results of Plate Count Tests

Type of Soil	Classical Sample	Sample Obtained With Sampler System
Brown Clay Loam	6.1×10^6	1.3×10^7
Silty Clay Loam	1.2×10^6	9.8×10^6



Soil #5 — Light Brown Clay Loam



Soil #6 — Silty Clay Loam

Figure 30. Growth Detection by the Turbidimetric Method

The data given in Table 8 are also consistent with the results given in the final report.

The results of the biological tests show that a sample obtained with the pneumatic sampler does not significantly bias the sample from a standpoint of biological content. The small amount of biasing that does occur is in the direction which increases the biological content.

5. APPLICATION AND RECOMMENDATIONS

The potential application of the pneumatic sampler is directly related to the degree of significance that can be associated with the acquired sample. The significance of sampling with this sampler is influenced by the following three factors:

1) Deviations between the composition of the collectable dust from that of the Martian surface in general

2) Local and regional anomalies in the concentration of specific components of the Martian dust

3) Preferential collection by the pneumatic sampler of specific components due to differences in their physical properties.

With regard to the first of these items, the representativity of the dust for the Martian surface in general, no generalization is possible from a dust sample with regard to the areal distribution. It is, for example, conceivable that extensive terrains occur of outcropping sedimentary, igneous, or even metamorphic rocks. The diagnostic traces of these rocks would probably largely be lost in the fine-grained, unconsolidated deposits on the Martian surface as far as crystal structure of the component minerals is concerned. Furthermore, the chemical average composition of the source rocks that the Martian dust would represent could largely have been permuted, particularly by cometary contamination during planetary time, particularly if the amount of Martian dust produced during the totality of the evolution of the planet is small.

With regard to item 2, it appears that extensive chemical and physical segregation of the components can have taken place; salt deposits, oxide crusts and wind-sorted concentrates constitute a few examples. Analysis of a single sample from one site could consequently lead to strong over-emphasis of one group of components.

With regard to item 3 it is inevitable that segregation due to the sampling equipment takes place when sampling and collection by a gas stream is employed. For example, it is obvious that an upper limit in grain size must occur. This bias of the pneumatic sampler with regard to grain size has already been extensively verified. When grain size is discussed in this connection, it must be remembered that the parameters treated in Stokes' law or in hydraulic equations refer to the radius of round, smooth particles of a specified density. Consequently, the grain size will not be the only factor on the basis of which the sorting takes place, but also the density of the dust and its shape.

The present upper cutoff for the pneumatic sampler is on the order of 800 microns for sand particles having a density of 2.6. This cutoff might lead to a serious under-representation of residual materials of relatively large grain size. However, it must be remembered that the bias of the pneumatic sampler for low density small particles is one of the reasons for its suggested use for Martian life studies. As for the lower sampling cutoff in grain size, this would depend on the state of cohesion of the fine particles due to their own charge and to cementing precipitates.

The limitations under items 1 and 2 above are obvious and inevitable; however, their existence does not diminish the interest from a planetological point of view in a sample collected by the pneumatic sampler. The correct interpretation of any physical observations on the sample would not be jeopardized as long as the local character of the sample is taken into account. The significance will depend on the calibration of the collection device for various parameters of the type mentioned above and should not be difficult to carry out as a complement to the work already done on the pneumatic sampler.

Specific recommendations for further study concerns answers that are needed in order to proceed with the design of a sample acquisition system. Basically, the areas requiring further study can be divided into two categories: a thorough analysis including comprehensive testing of the pneumatic sampler for establishing the capabilities and limitations of this device under the revised Martian conditions, and a study leading to a definition of the general sampling requirements.

Establishment of the specific capabilities and limitations of the pneumatic sampler is necessary in order to select a type of sample acquisition system. Additional information needed includes:

1) The results of performance tests conducted on diverse native soils

2) A design analysis of the present pneumatic sampler to determine answers for questions such as what are the miniaturization limits, the reliability factors, and the interface problems that might exist with other apparatus.

3) The improvements that could be made on the sampler to yield additional information such as the nature of the surface, the time required to obtain a given dust sample, or the position from which the sample was collected with respect to the starting point.

A definition of the general sampling requirements for a Martian experiment is needed in order to select and design the best possible acquisition system. Once these requirements are established, trade-offs could be made as needed, an integrated systems approach could be used for designing the apparatus, and consideration could be given to potential interface problems. A study leading to a definition of requirements should include the following aspects:

1) The distance from the laboratory at which the sample must be collected. For example, contamination by retrorockets will probably be a prime factor in the distance requirement.

2) The size of the dust sample to be collected

3) The period of sampling

4) The frequency of obtaining a dust sample or a repeated sampling trial, provided a negative result is obtained on the first trial

5) The region from which the sample should be taken, i.e., surface, subsurface or atmosphere

6) The amount of information required in addition to the sample. For example, the pneumatic sampler might traverse a surface with only the high-velocity jets aerosolizing the surface and not obtain a significant sample. A second traverse might then be made with both the high-velocity jets and a rotating brush operating and a significant sample might be obtained. This type of information could be pertinent to biology or geology.

6. CONCLUSIONS

The objective of the work described in this report was to demonstrate the feasibility of utilizing a pneumatic sampler for the collection of soil particles under simulated Martian conditions. A pneumatic sampler powered by an air ejector was designed, built, and tested. It was demonstrated that this sampler could meet the following conditions:

1) Properly operate in a pressure of 5 millibars

2) Transport sand particles as large as 800 microns

3) Collect a soil sample at a rate of at least 15 grams per minute from a dry, sandy surface

4) Obtain a sample from typical soils which is not significantly biased with respect to particle size distribution or biological content for size distribution up to 800 microns

5) Traverse a surface with a sampler head for a distance of at least 10 feet from the main sampler unit

6) Sample continuously for a period of at least 10 minutes.

In summary, the pneumatic sampler could be highly useful in collecting a sample of planetological significance, particularly during early missions where the weight limitation is particularly stringent. The significance and interpretability of the sample is largely dependent on the accurate knowledge of the hydrodynamic characteristics of the sampling device, and definition of its limitations with regard to shape, density, and size distributions of the particles in the sample, as compared to the corresponding distributions in the source.

7. REFERENCES

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2) General Mills, Inc., Electronics Division. Report No. 2277.* Investigation of an air ejector pump for high altitude sampling systems, by A. R. McFarland. Contract AT(11-1)-401. Final Report, May 15, 1962. (This contract has been novated, naming Litton Systems, Inc., Applied Science Division as successor in interest to General Mills, Inc.)

3) General Mills, Inc., Electronics Division. Report No. 2391.* Study of a large-volume impactor for high altitude aerosol collection, by A. R. McFarland and H. W. Zeller. Contract No. AT(11-1)-401. (April 1, 1963).

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5) Green, H. L. and W. R. Lane. Particulate clouds, dusts, smokes and mists. 2nd ed. Princeton, N. J., Van Nostrand, 1964.

*Information regarding this report may be obtained by contacting the Applied Science Division, Litton Systems, Inc., 2295 Walnut Street, St. Paul, Minnesota 55113.

APPENDIX

OPERATING INSTRUCTIONS
FOR THE
PNEUMATIC SAMPLER

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Preparation of the pneumatic sampler consists of the following steps:

1) Depress the lock on the governor housing to prevent the governor from turning. Turn the retriever wheel in a clockwise direction until 2 or 3 turns of the spring remain on the take-up drum (the smaller of the two drums). Figure A-1 shows the lock and the spring motor.

2) Next the transport tubing is installed (Figure A-2). Release the lock on the governor housing so that the retriever wheel starts to rotate. The tubing is fed through the guide cone into the groove between the retriever and idler wheel and around the retriever wheel in a counterclockwise direction. The tubing is then fed through a groove between the retriever wheel and a second idler. Next the tubing is passed under the guide cone tubing and is attached to the cyclone separator. The lock on the governor housing is depressed so that the spring motor cannot rotate. Care should be exercised so that the two sections of the tubing do not bind where the tubing enters the guide cone.

3) The cam lever on the flow-starting valve is set in its off-position. This lever is set by manually turning the retriever wheel in a clockwise direction until it can be raised into one of the two V openings in the wheel (Figure A-2).

4) The ejection subsystem requires two CO_2 cartridges which are inserted in the sampler head by removing four screws. These cartridges are 3/4 inch in diameter, 2-1/2 inches long and contain 8.5 grams of CO_2.

5) The next step is to install the transport tubing and sampler head in the storage cone (Figure A-3). The transport tubing is loosely wound in a clockwise direction on the storage cone. The winding process starts

with the tubing from the guide cone being wound onto the large end of the storage cone. Next the penetrator mechanism is cocked by pulling out a rod located on the back of the sampler (Figure A-4). As a safety measure the cocking rod is left in this position until the sampler is ready to be operated. The sampler head is then inserted into the penetrator mechanism until the indicating marks on the sampler head line up with the end of the sample head guide.

6) The gas storage cylinder is removed from the sampler by closing the shut-off valve next to the cylinder and removing the fitting directly adjacent to the pressure regulator. The cylinder is filled with 1 pound of liquid CO_2. The cylinder is replaced in the sampler and the shut-off valve opened.

7) Next the collection chamber is installed on the cyclone separator. Care should be exercised that this chamber is tightly attached since a leak at this location will affect the gas flow rate through the transport tube.

8) The last step is to attach the starting cable and remove the cocking rod from its safety position.

9) Operation is begun by depressing the starting switch on the attached cable.

10) After operation remove the collection chamber containing the Martian dust from the cyclone separator.

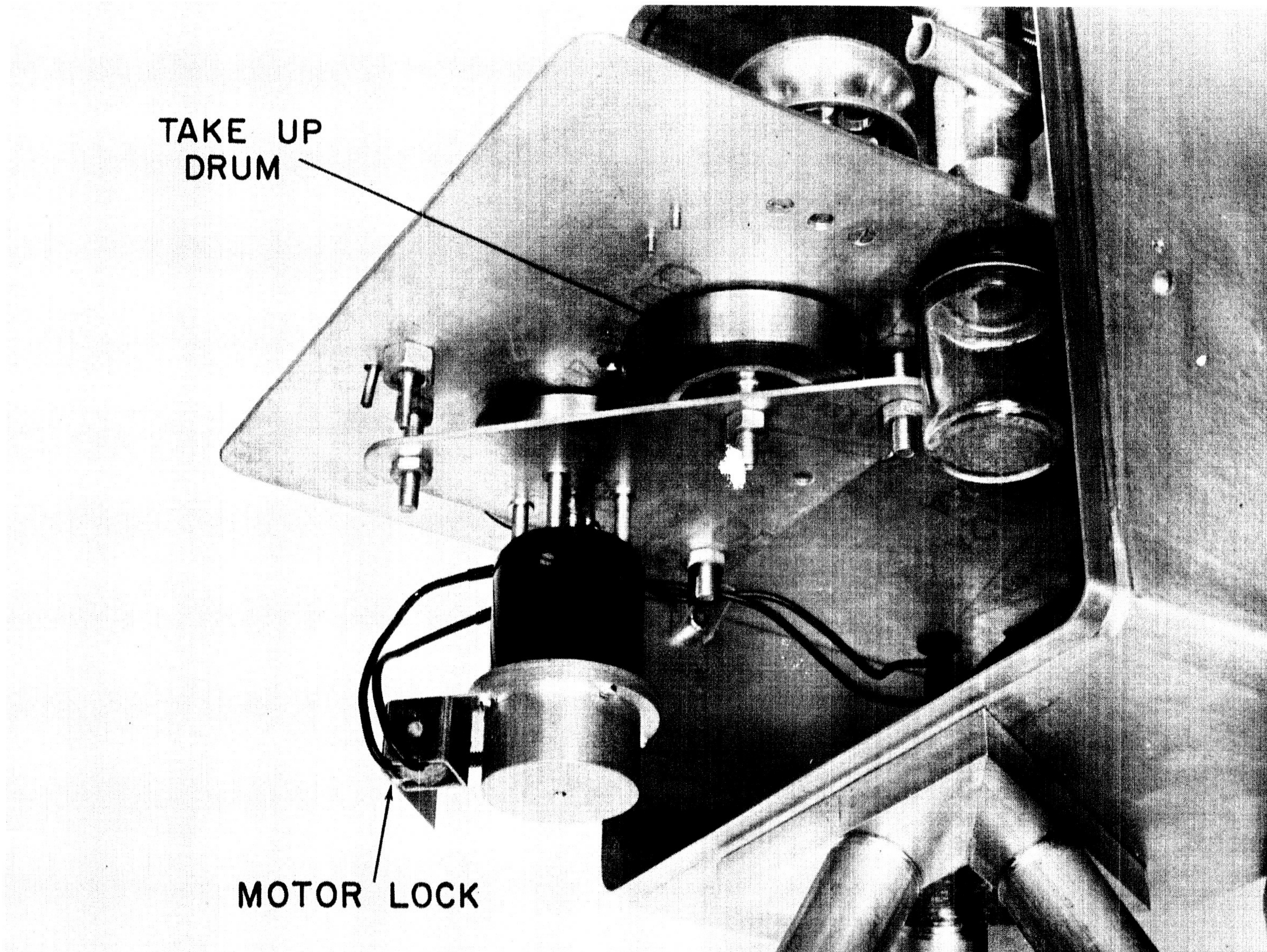

Figure A-1. Bottom View of Retrieval Subsystem

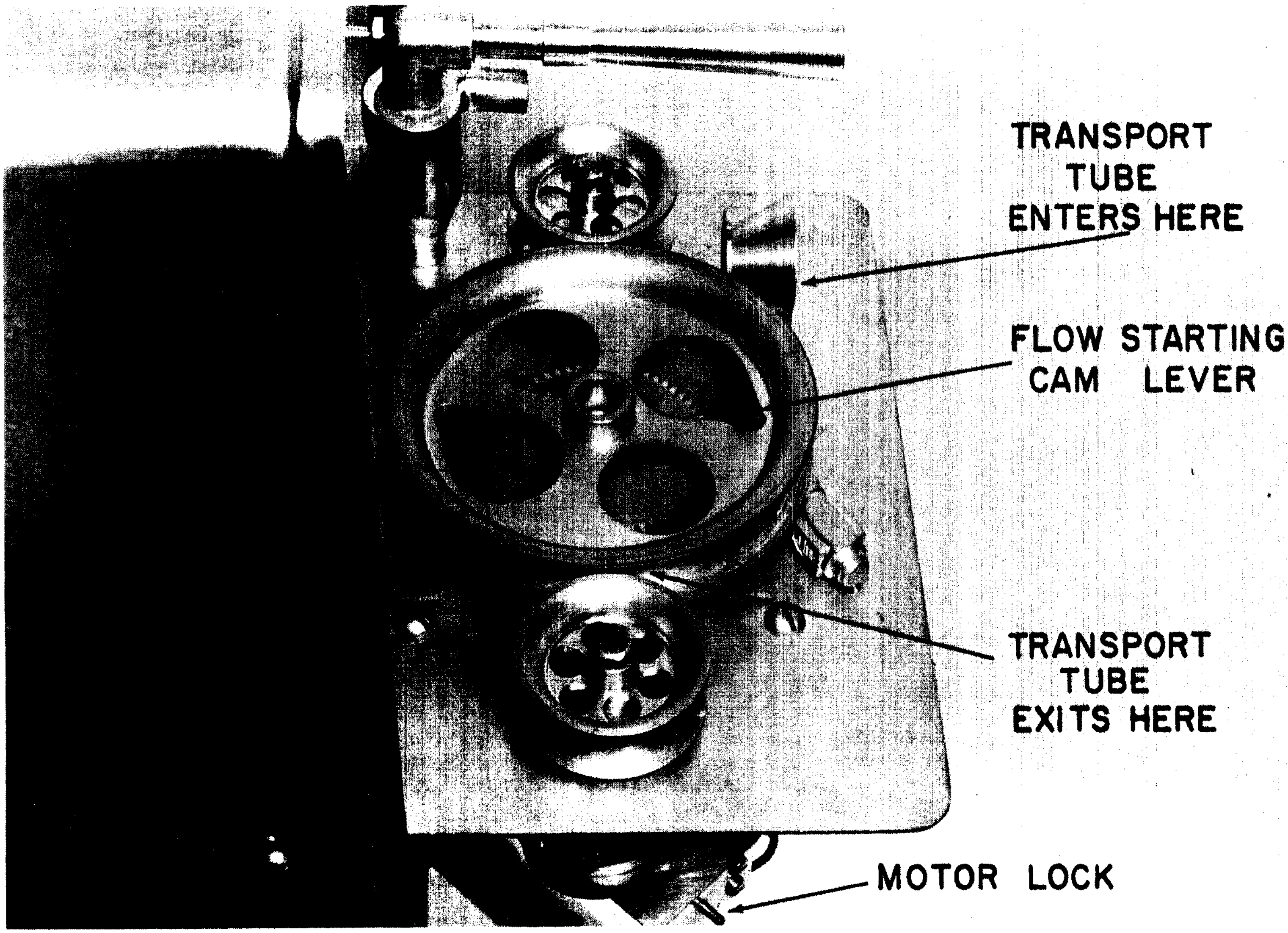

Figure A-2. Top View of Retrieval Subsystem

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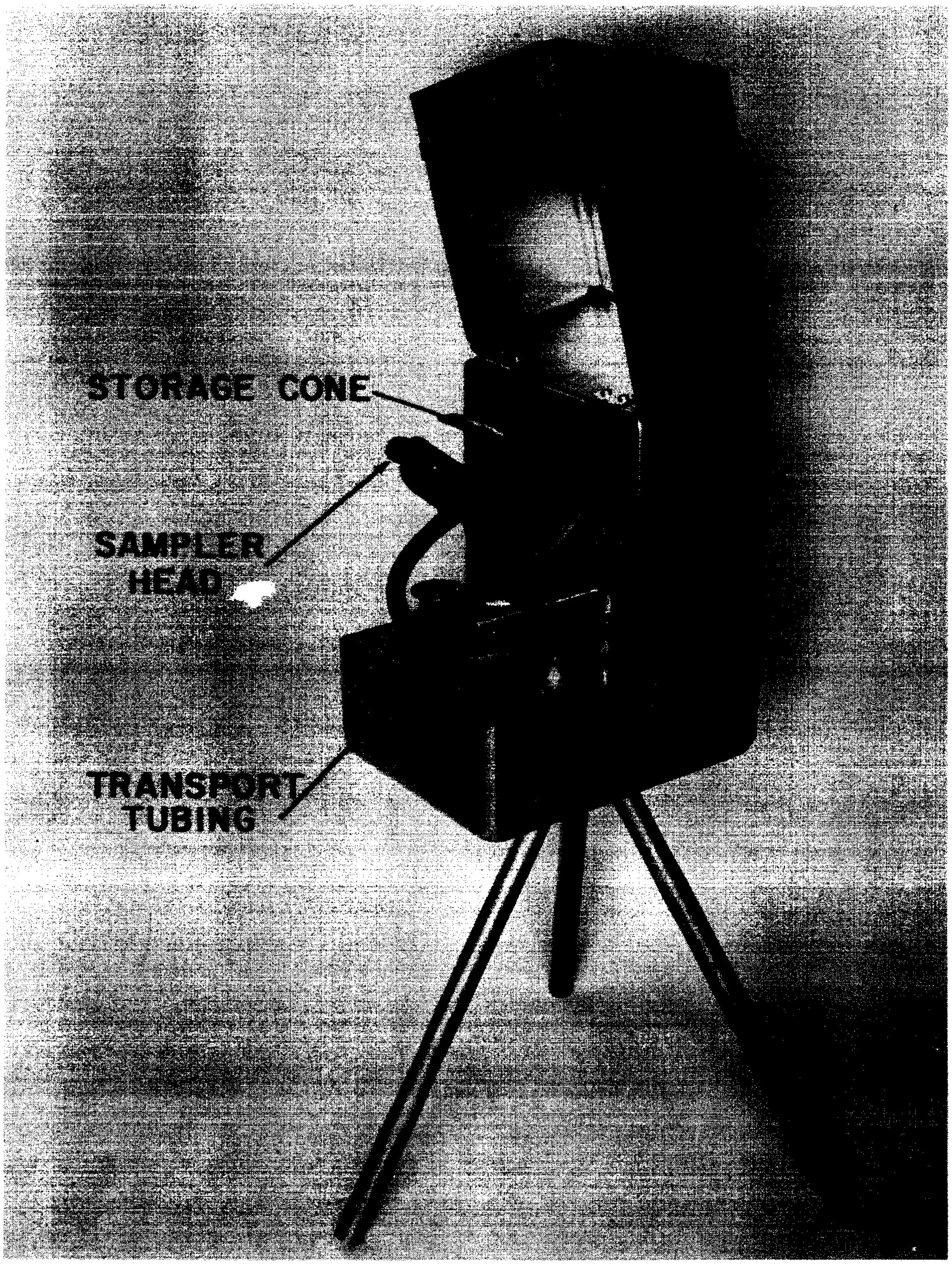

Figure A-3. Pneumatic Sampler

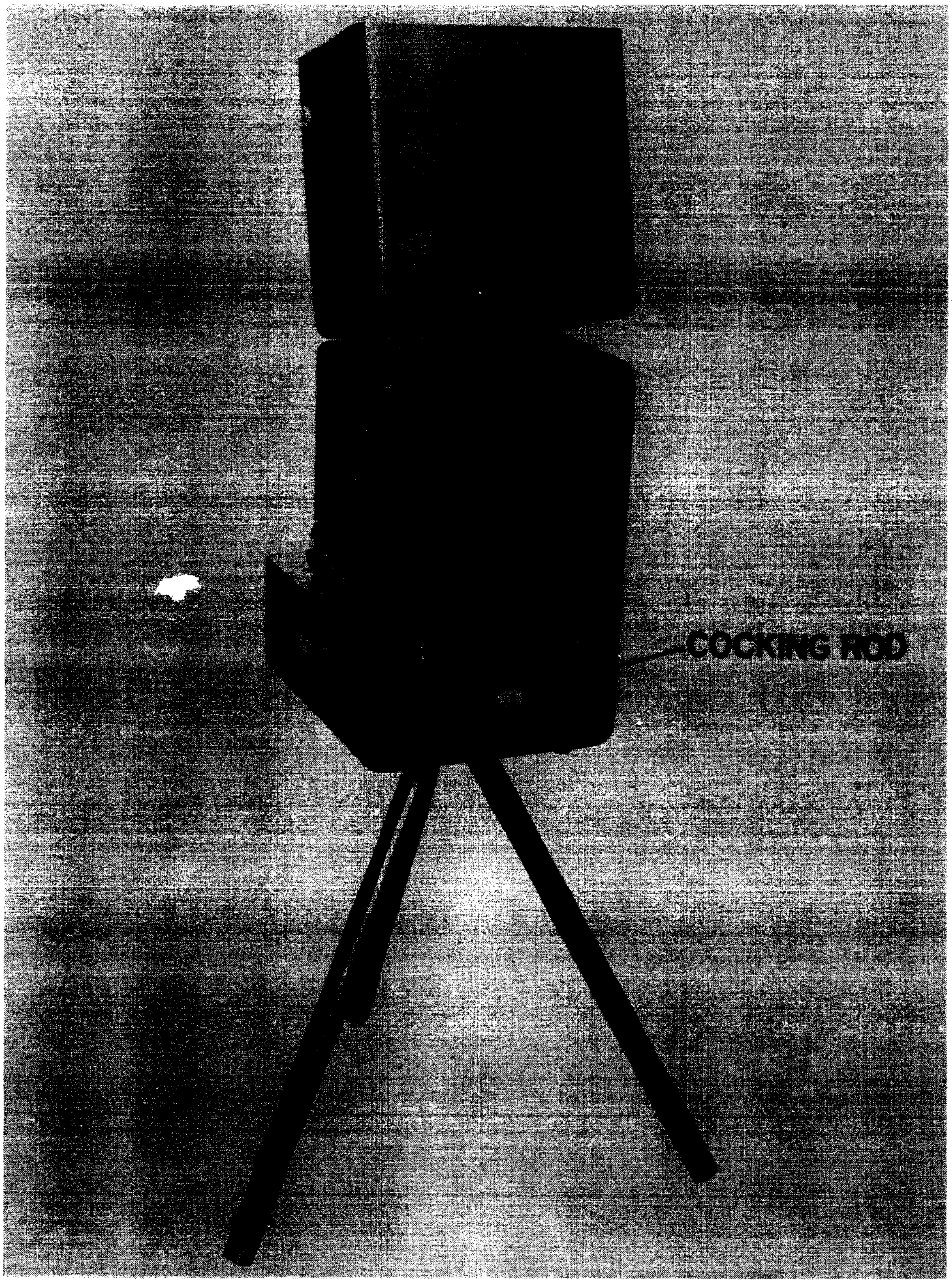

Figure A-4. Cocking Rod Mechanism